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Textiles: Some Technical Information and Data IV: Sewability, Sewing Needles, Threads and Seams

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INDEX

Page

1. INTRODUCTION 1
2. THE MACHINE 4
   2.1 Machine Speed 4
      2.1.1 Ways of Reducing Needle Heat 6
   2.2 Machine Admustments 6
3. THE NEEDLE 8
   3.1 Needle Characteristics 8
   3.2 Needle size 12
   3.3 Needle Surface and Finishes 14
4. STITCHES AND SEAMS 17
   4.1 Seam Cracking 21
   4.2 Seam pucker 22
      4.2.1 Further hints on how to prevent or reduce puckering 27
   4.3 Seam slippage, strength and extension 27
5. THE FABRIC 32
   5.1 Fabric Sewability 33
   5.2 Fabric lubrication and finish 39
6. SEWING THREADS 42
   6.1 Sewing thread requirements 42
   6.2 Types of threads and their properties 51
      6.2.1 Cotton threads 51
      6.2.2 Synthetic threads 53
         6.2.2.1 Textured threads 57
         6.2.2.2 Monofilament threads 58
         6.2.2.3 Multi-filament threads 58
         6.2.2.4 Staple threads 60
         6.2.2.5 Corespun threads 61

6.2.2.6 Auxiliary threads 64
6.2.2.7 Special purpose threads 64
6.3 Yarn Twist 71
6.4 Sewing thread lubrication 72
6.5 Finishing of sewing threads 75
6.6 Sewing thread size 76
6.7 Knots in sewing threads 78
6.8 Sewing thread breaks 79
6.9 Testing sewing threads for sewability 79
6.10 Effect of sewing thread on needle temperature 80
6.11 Thread make-up 82
7. MISCELLANEOUS 82
8. THE MEASUREMENT OF FABRIC SEWABILITY 84
9. REFERENCES 86

TEXTILES: SOME TECHNICAL INFORMATION AND DATA IV: SEWABILITY, SEWING NEEDLES, THREADS AND SEAMS.

by L. HUNTER and M.P. CAWOOD

INTRODUCTION

On 1st April, 1979, SAWTRI launched a Clothing and Making-up Technology Department and it was, therefore, considered a worthwhile exercise to compile scientific and technical data and information related to this field since tremendous strides have been made over recent years in extending our knowledge, information and understanding in this area. This report concentrates on matters related to sewing performance (sewability) and sewing threads. The authors have attempted to compile a data source which could be used as a basis of reference by the industry and quality and research laboratories in general. Much of the information has been reproduced directly from the original source.

The introduction of needle and thread into multilayers of fabric must be considered the single most complex phenomenon in the textile process from the conversion of raw fibres to the completed garment[1]. Making-up is usually the final process in a long series of manufacturing processes and a garment spoilt at this late stage, by bad seaming for example, represents a waste of time, effort and material[2]. Sewing is both the most labour intensive operation and potentially the source of most production quality performance problems in garment manufacturing[1]. Seam damage is regarded as a serious cost problem in textiles[3] and often only shows up after the garment has been worn.

In spite of the long history and development of sewing techniques, problems frequently arise as a result of faulty sewing[4], sewing damage[2], seam failure[1], seam damage[5], seam slippage[1,6] puckering[6], sewing needle damage[6] or needle cutting[1], fusing damage[1], etc. Hatra has recently published a Sewing Room Technical Handbook[7] which contains useful information on seams, stitches, puckering and sewing damage.

Generally sewing damage can be classified into two classes[3,8,9,10] viz.:

1. that caused by excessive needle heat, i.e. fusing damage

2. that due to mechanical damage, i.e. yarn rupture. The latter is more frequently encountered and also more noticeable and troublesome[9]. Yarn rupture and fusion damage are caused by high friction (i.e. lack of yarn mobility) in the fabric[3,10] since this can lead to either high yarn-to-needle friction and, therefore, needle heat, or else it can prevent "robbing" leading to yarn snapping[3,10]. When fusing damage occurs, actual sewing of the seam is likely to be difficult because melted polymer tends to stick to the needle

and, when it solidifies in the eye, gives rise to thread breakage.

Sewing or stitching damage is also referred to as *needle cutting,* defined as the formation of holes in sewn fabric caused by breaking, fragmentation or severing of the loops or yarns of the fabric by the sewing needle during the seaming operation[11]. Generally it does not manifest itself immediately but only after the garment has been worn.

In double jersey fabrics, needle cutting can be caused by needle heating or by the impact of the needle severing all or some of the filaments constituting a loop in the fabric[11]. The second cause is the more prevalent[11].

In a knitted fabric the yarn can be ruptured either as a result of the needle penetrating the yarn itself or the loop and inadequate expansion of the loop (stitch)[12]. To penetrate the fabric without causing damage, the needle must pass through a knitted loop and generally this necessitates an increase in the size of the loop (see Fig. 1)[13,14]. This means yarn has to be robbed (borrowed) from adjacent loops and if yarn-to-yarn friction is high the yarn may rupture because of excessive inter-yarn frictional forces[3].

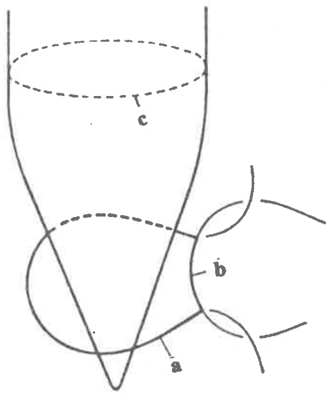


Fig. 1 – The needle pushing into the loop[14]

The variables of needle size, shape and surface, the properties of selected threads, sewing speed and seam design, can all be expected to influence the seam appearance and properties[1]. A Table (Table I) of needle/thread/fabric correlation is reproduced from a publication[14].

Elsewhere it was reported[15] that sewing damage can be related, directly or indirectly, to one or more of the following factors:

TABLE I

NEEDLE/THREAD/FABRIC CORRELATION CHART (SEWING MACHINE MAKERS' RECOMMENDATIONS)[14]

Natural fibres

Needle size		Needle point	Stitches		Sewing thread		Fabrics to be sewn
Singer	Continental	dia. (mm)	per inch	per cm	Cotton	Silk	
9-11	70-75	0,67-0,72	14-16	5,5-6,3	70-80	100-120	Organdie, chiffon, lace, lawn
11-12	75-80	0,77-0,82	12-14	4,7-5,5	50-60	80-100	Satin, poplin, taffeta, linen
13-14	85-90	0,87-0,92	12	4,7	36-40	60-70	Dress wool, velvet, jersey, flannel, corduroy, denim
16-18	100-110	1,02-1,07	10-12	3,9-4,7	36	50-60	Tweed, velour, mohair, canvas
19-21	120-130	1,17-1,32	8-10	3,1-3,9	20-24	40-45	Tent, canvas, sailcloth, waterproof

Synthetic and man-made fibres

Needle size		Needle point	Stitches		Sewing thread	Fabrics to be sewn
Singer	Continental	dia. (mm)	per inch	per cm		
9-10	70-75	0.67-0.72	14-16	5,5-6,3	130-150	Chiffon, taffeta, seersucker, lawn
11-12	75-80	0.77-0.82	12-14	4,7-5,5	100-130	Pique, brocade, nylon, lawn
13-14	85-90	0.87-0.92	12	4,7	80-100	Slub satin, jersey, velvet
16-18	100-110	1.02-1.07	10-12	3,9-4,7	60-80	Foam-backed, showerproofed, plastic coated, industrial nylon
19-21	120-130	1.17-1.32	8-10	3,1-3,9	40-60	Sleeping bags, fur fabrics, resin-treated fabrics

(a) The *machine:* Speed, needle movement, adjustment and condition of the machine.

(b) The *needle:* Diameter, shape of the body and point, surface (chrome etc.), cooling and lubrication, accidental deformation.

(c) The *stitch:* Type, length, length of the seam, adjustment and density of the stitch.

(d) The *fabric:* Fibre type, structure, density (tightness), dyeing treatments, number of layers sewn, fabric condition (regain), atmospheric conditions but more important the amount and type of *lubricant* present on the fabric at the time of sewing.

(e) *Sewing thread:* Natural fibres/synthetics, staple or continuous filament, finishing treatments, over-lubrication on the machine.

2. THE MACHINE

2.1 Machine Speed

Sewing damage can occur as a result of needle heating caused by friction between needle and fabric[4,14] when the needle passes through the fabric at high sewing speeds. Needle heating will obviously increase as sewing speed increases and can be a very serious problem when sewing synthetic fabrics on high speed machines[4, 14], since the needle temperature can rise to above the fusing point of the fabric or synthetic sewing thread (if used), resulting in a damaged fabric or sewing thread[4]. *Machine speed* is apparently the largest single influence of needle temperature[14, 16].

It is claimed that less than 5% of sewing failures are due to fusing of fibres caused by the temperature of the sewing needle exceeding the melting point of thermoplastic fibres and, generally, this type of damage can be reduced by reducing the sewing speed. Needle heating has also been studied in various other articles[17-20], it being concluded that sewing speed is of major importance in determining needle temperatures. Thermal effects are generally visible in the last third of the seam[15].

Needle heating is generally measured in two ways, viz. by infra-red pyrometry or by attaching a thermocouple to the sewing needle[21]. With the use of synthetic threads and sewing speeds in excess of 5 000 stitches/min, thermal damage can be a severe problem, with needle temperatures increasing linearly with increasing sewing speed within the range of 2 500 — 5 000 stitches/min[22]. Heat was found to increase at a rate of 4,44°C per 100 stitches/min increase in sewing speed[16]. For example, increasing the sewing speed from 2 500 to 3 500 stitches/min raised the needle temperature by 88,8° C. These results pertain to the steady state temperature of the needle i.e. after at least 10 minutes of sewing[16]. In normal practice, however, a commercial machine is rarely operated for longer than six to seven seconds at a time, even for very long seams[16], allowing therefore for some heat dissipation. A cycle of five seconds sewing followed by five seconds rest, etc., would enable the needle to maintain a temperature that is 85% of the maximum[16]. However, elsewhere[14] it is claimed that the sewing needle can attain its equilibrium temperature within 3 to 10 seconds depending upon many factors such as sewing speed, number of fabric plies, etc. Needle temperature, upon stopping, is reduced to nearly half in about four seconds[15].

Reducing the needle velocity during its contact with the fabric can reduce needle temperatures by about 50° C although other workers found the differences to be only 2 to 12° C[14]. Radiation plays a minor role in needle cooling, the most important being conduction followed by convection[14]. Convection forms the largest component of energy loss from a needle during normal sewing and can be increased even further by directing cool air onto the needle[14], temperature reductions of 20-50° C having been obtained.

Vapour sprays, e.g. water or lubricant, applied during sewing can reduce needle temperatures significantly, particularly when a lack of fabric lubricant is the cause of sewing problems, although fabric staining is a danger[14]. It is apparently the only attachment really effective for reducing needle temperature by acting as a coolant[8,23] and can also reduce mechanical damage although proper fabric lubrication is preferred[8]. Needle cooling techniques, with the exception of the vapour spray, are regarded as short term solutions to needle heating[24]. They generally only reduce needle temperature slightly. Fabric finishing (lubrication) is regarded as the long-term solution, with vapour spray cooling an alternative for fabrics which are totally unsuitable for lubrication[24]. Elsewhere[25] it was suggested, however, that compressed air is probably the most successful form of needle cooling and it is extensively used. It was stated in another article[16] that probably the greatest single reduction in needle temperature under any sewing situation has been achieved by blowing a stream of air over the needle itself although operators complain that their hands become too cold[26]. A hollow presser foot can eliminate this by allowing the air to pass through it. One manufacturer uses the hollow needle bar as a piston, compressing air and pushing it to the needle shank at high speeds. The needle contains an additional groove which leads the air to the needle point. They claim this allows the sewing speed to be increased by 25%[26].

The dexterity of the human hand has been found to reach its maximum speed limit (and effectiveness) at speeds equivalent to those encountered at a sewing machine speed of 5 500 stitches/min[27]. If properly trained operators are used, there should be no need to reduce sewing speeds when switching to knitted fabrics[32].

2.1.1 Ways of Reducing Needle Heat

To summarise then, ways of reducing needle heat are:

1. Reduce sewing speed where feasible[12,14,16].
2. Use a cycle involving shorter periods of operation and longer rest periods[16].
3. Use needles with a different surface (e.g. Kooltorr or dark matte finish as opposed to polished chrome, nickel or steel)[16]. A coated needle can be used although the coating generally wears off quickly[12].
4. Reduce needle size[12]. A needle should be used that is designed to reduce needle friction, e.g. bulged eye or reduced blade[12] although it is claimed[16] that point type and other design variations will have a negligible effect.
5. Thread and cloth lubricants should be beneficial[12,16] although the thread is generally lubricated during manufacturing[12].
6. Decrease the depth of needle penetration[16].

A combination of the above could apparently reduce needle temperature by as much as 25%[16].

7. Employ an air-cooling system[12,14,16] and a lubricant at the point of sewing[12].
8. Keep seams as simple as possible, multi-plies lead to high needle temperatures[14].
9. Maintain the sewing machine in good working order, keeping thread tensions and presser-foot pressure as low as possible[14].
10. Use corespun or staple fibre threads as opposed to continuous filament threads[14]. Generally, the presence of thread, particularly spun polyester, tends to reduce needle temperatures[22].

2.2 Machine maintenance and settings

Sharp edges and burred parts in the sewing machine can cause damage[8]. Sharp edges on the *feed dog* can cut the yarns in the fabric, the damage usually being located to one side of the seam. A damaged *presser-foot* can damage a fabric in the same way as a damaged feed dog. Any burred or sharp places on the needle or throat-plate can significantly affect sewing damage with the needle point length and number of plies also playing a rôle[28]. All surfaces on the sewing machines should, therefore, be inspected periodically and all burrs polished[29].

Excessive presser-foot pressures can inhibit yarn movement and can aggravate needle damage although insufficient presser-foot pressures can lead to erratic feeding of the fabric causing non-uniform stitch lengths and abraded areas in fabric where the feed-dog has rubbed against the fabric instead of moving it forward[29]. Rounding out the top of the *throat plate* needle hole and the underside of the *presser-foot* behind the needle can reduce needle cutting by increasing the mobility of the fabric[29], although if this is excessive, flagging of the fabric may be caused which could also result in skipping of stitches. Poor maintenance, particularly the use of damaged needles, can also lead to seam damage[3].

In one publication[30], it is stated that a large throat plate hole allows greater freedom of the yarns to slip over the sewing needle and so tends to reduce damage. The feed dog should be fine-toothed and set with only the teeth protruding above the throat plate at its highest point. Presser-foot pressure must be as low as possible but must still ensure even transportation of the plies of the fabric throughout the seam length[31]. In another publication[8], it was mentioned that the throat-plate hole diameter should be double the diameter of the needle.

For knitted fabrics, feed dogs with finer teeth are required than those used for woven fabrics[32]. Too high feed dogs can cause snags and cut the fabric while too heavy feed dogs can cause stretching and distortion of the bottom ply. For fine knits, a feed dog with 8,7 teeth/cm has been found suitable and 5,5 teeth/cm for heavy knits. Feed dogs should be set a half a tooth above the throat plate for knits and up to three-quarters of a tooth above the throat plate at its highest for heavy knits[32].

Changing the depth of penetration has a significant effect on needle temperature under a given set of sewing conditions, there being an increase of 10,6°C for each additional 0,25 mm increase in needle penetration over a range of "normal penetration depths"[16]. Grinding a dent in the bottom of the presser-foot in the part nearest the needle can reduce seam damage since it allows the fabric greater mobility as the needle penetrates it[13].

Sewing machine feed mechanisms are described in a publication[33] by the Clothing Institute.

3. THE NEEDLE

3.1 Needle Characteristics

Steps involved in the manufacture of sewing needles have been discussed by Blackwood[34] and various types of sewing needles are reported in a recent article[35]. More than 20 types of sewing needles are available for overlock machines[36].

Fig. 2 illustrates the essential characteristics of a sewing needle[14].

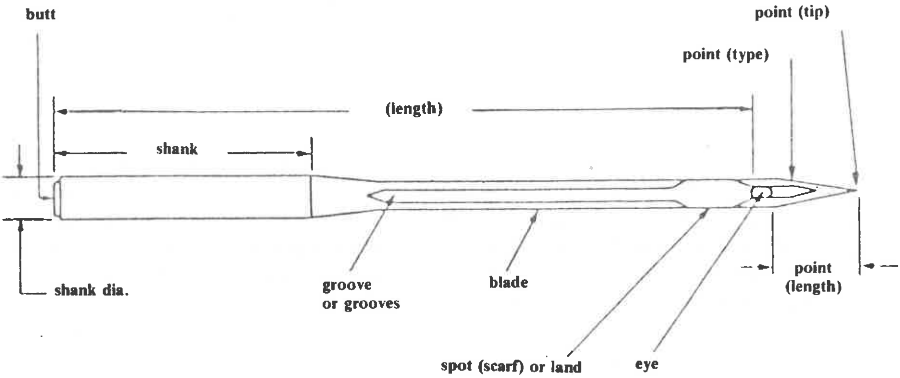


Fig. 2 – Terminology of the various parts of a needle[14]

The *shank* is the upper part of the needle by which it is clamped, and it frequently has a larger diameter than the rest of the needle to ensure good rigidity and strength[14]. The *blade* is the portion of the needle between the *shank* and the needle *eye*. It sometimes has a reduced size over part of its length to reduce needle-to-fabric friction, although care must be taken not to weaken the needle excessively in doing this. Different cross-sections have also been tried to reduce friction[14]. Needles with a bulge at the eye have been developed to produce a larger hole and so reduce friction between the rest of the needle and the fabric. Needles with tapered blades have also been developed for the same purpose[14]. The *long groove* is cut into the *blade* to take the thread as it passes to the eye. Groove widths are generally greater than groove depths, with the former generally 34 to 54% of the blade diameter and the latter generally 24 to 43% of the diameter. The groove dimensions should exceed the diameter of the sewing thread[14]. The "after-sewing" diameter of threads can be 3 to 30% larger than their "pre-sewing" diameters[14]. The *scarf* (spot or land) is a clearance cut in the blade just above the *eye*. Its purpose is to permit a close setting of the shuttle, hook or looper to the needle[14].

The *eye* which extends through the blade from the long groove side to the opposite short groove side, is usually made proportional in size to that of the blade, although sometimes it can be smaller or larger. The thread should pass freely through the eye but not too loosely since the latter condition can interfere with proper loop formation[14]. Nevertheless, large variations in eye dimensions with needles of the same nominal size occur. Needles which are bulged in form around the eye region but have a narrow shank (see Fig. 3) are frequently recommended for sewing knitted fabrics when needle heating is a problem[14]. It has also been reported elsewhere[8] that bulged-eye needles can reduce needle temperatures slightly but hardly affect mechanical damage. Needle eye lengths are generally three times the eye width although it may be more than this for heavier threads[37]. Often a circular eye is used when sewing rubber threads[37].

The *point* of the needle is shaped to achieve the most suitable penetration of the material[14]. *Needle point* shapes can be divided into two main groupings[34] : 1) The *cloth point* styles in light, medium and heavy *set* points, fine, medium and full ball-points, *slim* and *stub* points, *eccentric* points and *bulged-eye* type needles; 2) The *leather point styles* — triangular, diamond, cross-spear, spear, the various twist points, wedge and cross points[34]. The most common needle point styles are[25], however : 1) *Cloth point* which is sharp tipped and the most common in the clothing industry; 2) *Ball point,* frequently used on rubberised materials and 3) *Cutting point* needles, which are mainly used in leather and similar materials. For the clothing trade, sewing needles generally have *round points* comprising of different types of set tip points, four types of ball points (light, medium, heavy and extra-heavy[11]) and lastly *rounded set tips* for special stitching conditions[26]. The coarser the fabric yarns the more the sewing needle point should be rounded.

The point-tip of a rounded needle (Fig 3) is very slightly blunted (or "set") to strengthen the point against distortion or breakage. Sharp-tip round-point needles are generally recommended for most woven fabrics while for fabrics containing fine yarns or elastic threads, and also for many knitted fabrics, ball-point round-tip needles (Fig 3) are

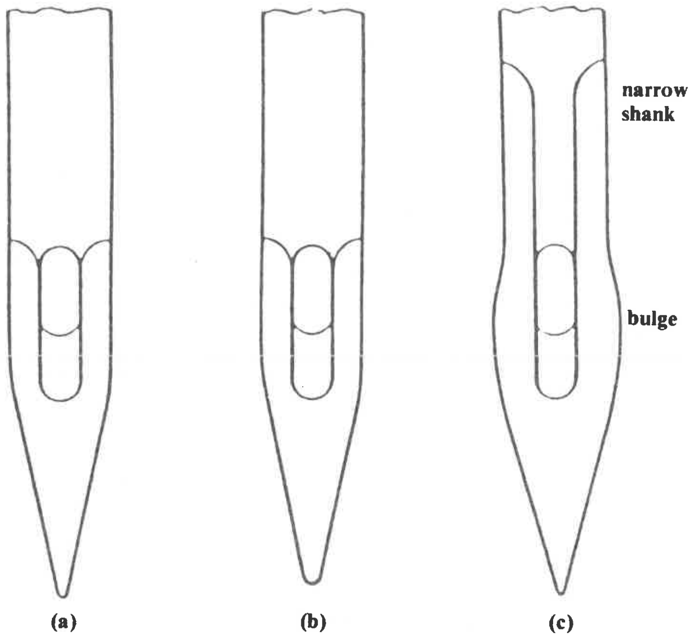


Fig. 3 – Types of needle tip.
(a) sharp tip needle,
(b) ball tip needle,
(c) bulged eye needle.

generally recommended[14]. The choice of fine, medium or full ball-point depends upon the ply construction and density of the fabric being seamed[34]. Defective or damaged needles can increase needle cutting (damage) considerably[34]. For coarse-gauge jersey, a *slim point* needle is often preferable since it will penetrate the fabric cleanly and not push the looser yarn down the throat plate hole[38]. For fine-gauge jersey a fine *ball-point* needle is recommended[14,39] since they tend to deflect the yarns rather than pierce them[4,14]. Even a size 10 (70 metric) needle has proved very satisfactory for light-weight stitching operations[38].

Knitted synthetics should always be sewn with *ball-point* needles to avoid cutting of the yarn. Elastic fabrics with core-spun rubber or elastic fibres should be stitched with heavy ball points. However, if a heavy *ball point* is used on too thin a needle it may cause needle deflection when stitching heavy fabrics and this could, in turn, lead to skipped stitches[26]. It is, however, suggested[36] that ball-point needles can give irregular hemming seams.

With uncovered elastic threads the friction between the threads and the blade could be so high that the elastic threads are twisted or pulled out as a loop. In such cases a very sharp needle is necessary so that it actually penetrates the elastic threads without really severing them[26]. When stitching very different fabrics together special compromise needles have to be used such as *rounded set tip* for a corset satin stitched to a coarse mesh elastic. The medium size *set tip* needle is used for the great majority of stitching operations in the clothing trade. Soft leathers, like the clothing trade, require needles with round points[26].

Short point needles are claimed to produce more yarn breakages than long-point needles[8]. Medium-ball and heavy-ball point needles should normally not be chosen for making-up fabrics because they are more liable to cause mechanical damage. They are often desirable, however, where yarn penetration is undesirable, for example fabrics containing rubber or Lurex-type yarns[8].

It is stated[39] that the greatest single fault in sewing lies with the sewing needle used. Elsewhere it is reported[40] that faulty needles are responsible for a greater percentage of garment returns than is generally accepted. Blunt needles, and too large needles are often associated with sewing damage[39]. A needle with a blunt or bent point may produce an acceptable seam on heavy worsted cloth but not on fabrics made from fine spun yarn or continuous filament yarn[12]. When the needle penetrates the bulked yarn in the fabric, some or all of the filament may be ruptured whereas when it passes through a loop which is too small for the diameter of the needle, yarn has to be robbed from adjacent needles and where this is not possible, the yarn breaks[12]. The ball point needle has proved to be the best overall performer for reducing needle cutting, although on some fabric constructions sharp point needles have been found more effective. The *blade* size can also affect the severity of cutting. Tapered blade needles of a given size have the strength of a straight blade needle one size larger[29].

The length of the needle point also plays an important part in needle cutting and needle heat[34]. Needle diameter is of primary importance in seam damage, with point length having a marked effect[30], the long point apparently being preferable to a short point. It is stated[30], however, that needles with a *sharp* or *fine* point give *less* damage than needles with a *rounded* point. Furthermore, only with a fine warp-knitted fabric have heavy ball-point needles proved of any real benefit. It is concluded that variations in *needle diameter*, which is of prime importance, may have led to the confusion concerning the relative merits of different needle points[30].

Needle point shape does not appear to significantly affect maximum penetration force or energy expended while bulged-eye needles reduce heat build-up due to frictional energy, a 22% reduction in temperature being mentioned[14]. Needle size did not appear to have a consistent effect on needle temperature and cyclic sewing operations (i.e. sewing followed by idle time) can reduce needle temperatures by about 10 to 15% compared to continuous sewing[20]. Point-type and other variations in needle design did not influence needle temperature[20]. Blade diameter was not consistently related to needle temperature and it is not always true that the smaller the needle the lower the needle temperature[16]. Needle/fabric friction can also be greatly increased if the hole in the throat plate is too large or is badly worn since the needle drags the fabric into the hole producing a jamming effect[41].

Needle penetration force and energy per stitch cycle increases markedly with increasing needle diameter[14] and needle temperature also tends to increase with needle size (diameter) although the general "rule of thumb", "the smaller the needle the lower the temperature" is not always true. Full ball-point needles generally lead to higher needle temperatures[14] and bulged-eye needles to reduced needle temperatures[14,42] but have little effect on sewing damage[42].

3.2 Needle size

Needle sizes are related in Table II[44]. The Continental (or metric) needle size refers to the diameter of the needle blade in mm (x 100). Schmetz uses this method whereas Pfaff multiplies by 10, Union Special sizes equal the blade diameter (cross-section of the needle at the eye) expressed as decimals of an inch ("Inch" system), whilst Willcox and Gibbs multiply this figure by 1 000 to get their size number. Singer and Torrington have a system of numbers from 6 to 31 with no apparent relationship to the needle diameter[37].

Too fine a needle, although reducing needle damage, can lead to excessive needle breakages in the case of a greater number of plies or heavier fabrics[31]. It has been suggested that for fabric masses up to 70 g/m², size 9/11 Singer or 65/75 metric will be suitable. For 70 to 100 g/m², size 11/14 Singer or 75/90 metric needles should be used. A corresponding throat plate is, however, necessary. Too large a throat plate can lead to lack of proper fabric control during the descent of the needle whereas too small a throat plate can lead to needle breakage when the needle is deflected ever so slightly[31]. Needles of nominally the same size can differ quite considerably, particularly at the eye area, this

TABLE II

COMPARISON OF NEEDLE SIZINGS[44]

Number system (Singer)	Inch system (Union Special) (inch x 10^{-3})	Metric (Continental) (mm x 100)	(Pfaff) (mm x 10)	Other number systems (Willcox & Gibbs)		Reece
8	019 chainstitch	50	5	4/0	—	6/0
8	024	60	6	2/0	—	—
10	028	70	7	1	—	3/0
11	029	75	—	—	—	—
12	032	80	8	2	—	2/0
13	034	85	—	—	—	—
14	036	90	9	3	—	0
15	038	95	—	—	—	—
16	040	100	10	4	—	1
18	044	110	11	5	—	2
19	047	120	12	6	—	3
21	054	130	13	7	—	4
22	060	140	14	8	—	5

in turn leading to differences in sewability[43]. Needle size should be reduced to a minimum provided excessive needle deflection and breakage are avoided[12]. Smaller needles could lead to a higher rate of needle damage and regular needle inspection is necessary.

Seam breakdown and laddering in knitted fabrics are mostly ascribed to the needle[38]. *Blunt* needles can also be a cause of seam damage[38]. Even a needle which has been damaged only slightly can cause havoc in a knitted fabric[45,46]. Some factories change their needles twice a day when sewing knitted fabrics[46].

The effect of needle geometry on the sewability of knitted fabrics has also been investigated by Braun[47], who found that the optimum needle could reduce sewing damage by as much as 35%. It is often a useful practical procedure to determine the needle size at which sewing damage first occurs and then to use a needle one size smaller for bulk production runs[42]. A size 12 ball-point needle running at 5,5 to 6,3 stitches/cm has been regarded as good all-round for knitted fabrics[48].

3.3 Needle Surface and Finishes

Orginally needles were not given a special surface finish but were merely highly polished steel. Then nickel-plated surfaces became popular, reducing rusting and giving a slightly harder finish but the plating tended to wear off, resulting in cloth damage[14]. Chromium-plated needles were introduced to overcome these problems and are widely used except for fine needles for which nickel plating is still used. Nickel plating is the cheapest but chrome plated needles are known to reduce friction between needles and synthetic fabrics[37]. Chromium plated needles are generally regarded as being best overall[8] and suitable for the clothing and shoe industries[171].

Needle surface affects the needle temperature significantly[16,20] (see Table III)[16] although certain surfaces (e.g. Teflon) wear off after a certain period resulting in a rise in temperature.

Chrome finishes avoid clogging of the needle's eye with the molten synthetic since it has anti-adhesive properties. When used with carbon steel it can increase the hardness of the cutting point increasing the life of the needle[26]. Some needles contain special non-stick finishes to overcome needle heating[37]. Non-metallic coatings such as PTFE can be applied so as to prevent the thread and fabric particles from adhering and clogging the needle groove and eye[14]. Nevertheless, once these finishes have worn off the needle surface is inferior to the chrome finish[26]. Special needle finishes which inhibit heat absorption have also been developed[14]. One such needle (Blukold) has blades with a roughened surface which reduces heat absorption while the shank has a

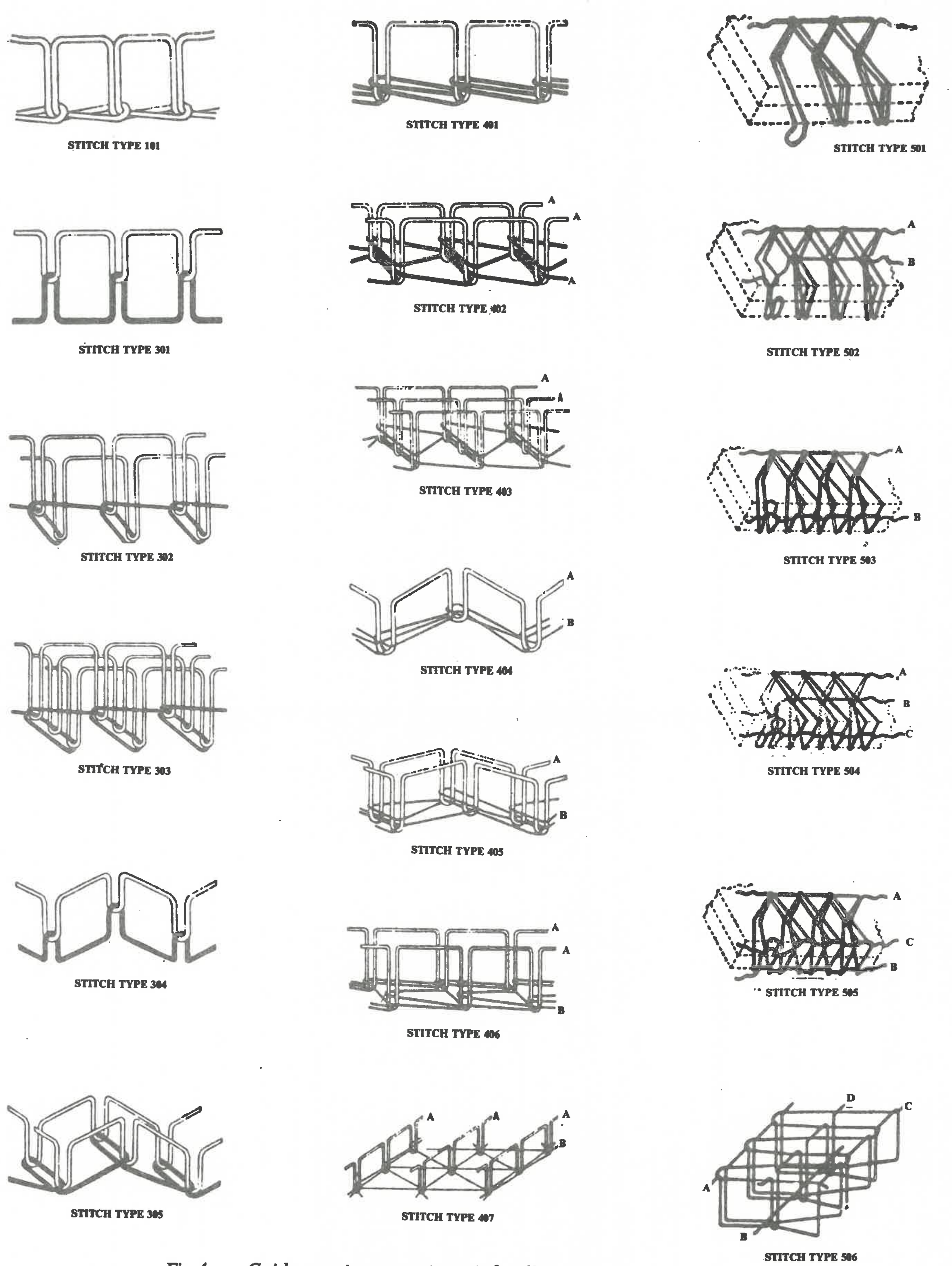


Fig 4 – Guide to primary sewing stitches [50]

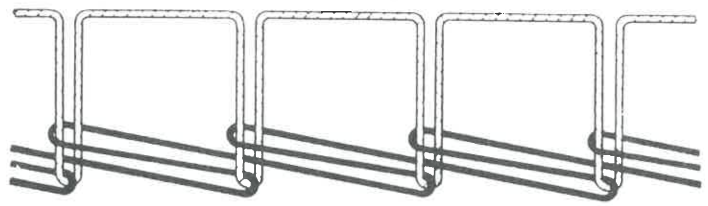
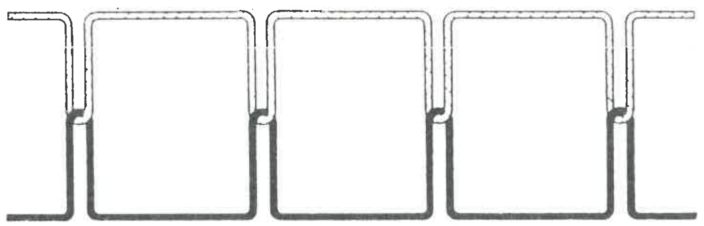
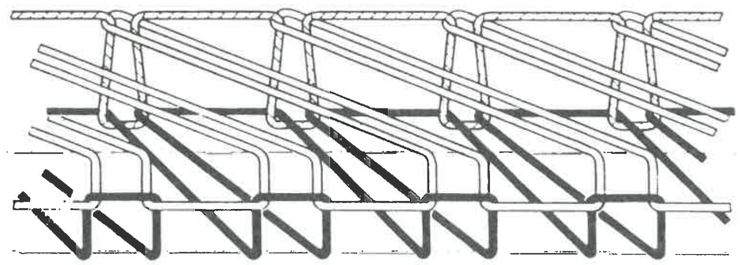
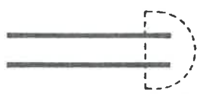
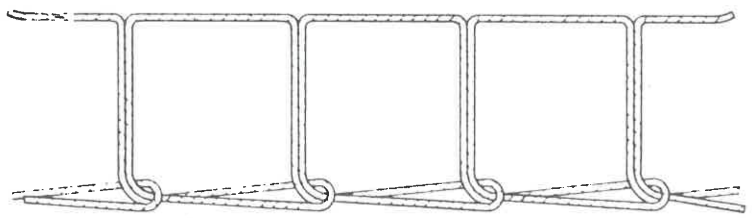
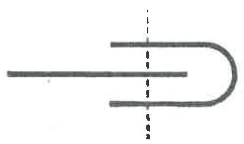
Stitch		Seam	Characteristics			Use
			Appearance	Physical properties	Durability	
Double locked chainstitch		 (and as immediately below)	Good	Lateral strength	Poor	Clothing with moderate extension warp knitted fabric; hemming
Lockstitch		 As sewn  Opened out	Good	Lateral strength	Good	Clothing with limited extension
Three-thread overlock		 As sewn  Opened out	Fair	High longutudinal extension	Good	Covering cut edges; clothing with high extension
Single-thread chainstitch linking			Good	High longitudinal extension	Fair	Loop-loop joining in highly extensible knitted fabrics

Fig 5 – Summary of various popular stitches, their application and properties[6]

TABLE III

EFFECT OF SURFACE FINISH ON MAXIMUM TEMPERATURE

Finish	Ave. temperature of 5 needles Temp. (30 s)	Temp. (2 min.)	Needle size
Kooltorr	639	648	88 x 1 size 16
Chrome	797	806	88 x 1 size 16
Nickel	718	725	88 x 1 size 16
Teflon	572	756	88 x 1 size 16
Dicronite	758	745	88 x 1 size 16
Silicon Dioxide	756	756	135 x 7 size 16
Molybdenum Disulfide	—	795	128 TAS size 16

smooth surface which assists heat transfer to the needle bar[14]. The sewing needle can also be kept cooler if it is coated with a silicone lubricant[49]. Normal needle finishes (e.g. matt) effect some reduction in needle temperatures. A dark-matte needle finish tends to reduce needle equilibruim temperatures although it generates more heat during sewing[14] (i.e. the heat dissipation increases). The hardness or temper of sewing needles can be affected by temperatures in excess of 200°C [34].

4. STITCHES AND SEAMS

A guide to the primary sewing stitches has been reproduced from an article[50] in Fig 4. In Fig 5, a summary of the most popular stitches, their application and their properties has been given[6]. Additional information on stitches and seams can be obtained in various articles[51,52,53]. Table IV is a guide to the basic sewing machine classes and stitch types[49].

For knitted fabrics, it is often important that the seams should be flat, neat and non-bulky with the lockstitch seams best in this respect, followed by the 2-thread chain-stitch[54]. The overlock seam is, however, also frequently used[54]. Two articles[55,56] compare the lock-stitch and two-thread (double-locked) chainstitch as far as economy and performance are concerned, it being concluded that no clear-cut rules can be stipulated[56].

The *lockstitch* is used in seaming warp-knitted shirting fabrics and also fine jersey fabrics where the raw edges have been previously

TABLE IV

GUIDE TO BASIC SEWING MACHINE CLASSES[49]

Machine Class	Stitch Types Produced	Applications
Chainstitchers	Type 101	Seaming and hemming, edging label sewing.
Lockstitchers	Types 301, 302, 303, 304, 305	Seaming, bar tacking, ornamental sewing Mostly used in sewing woven apparel, upholstery.
Doublelocked stitchers	Types 401, 402, 403	Seaming operations requiring durable and elastic seams.
Zig-zag stitchers	Types 404 and 405	Ornamental sewing, butt seaming.
Overedgers	Types 501, 502, 503 504, 506	Overlocking, overseaming, serging. Popular unit for sweaters, knit shirts, other knitted outer apparel.
Flat seamers	Types 601, 602, 603 604, 605, 606	Edging and covering, seaming. Especially used on underwear, lingerie, other intimate apparel.

overseamed to prevent ravelling[54]. In the "balanced" lockstitch seam, the inter-actions of the top and bottom threads are located ideally at the interface of the top and bottom fabrics and both threads are of equal length[54]. The *two-thread chainstitch* (double-lock chainstitch) is increasingly replacing the lockstitch mainly because of its greater extensibility and the fact that it does not run all that easily[54]. The chain stitch (type 101 to 106) is tight and elastic as well as being neat and relatively flat in appearance, making it appropriate for seaming fully-fashioned sweaters and similar knitted garments[49].

The *overlock* seam is possibly the most widely used in the making-up of knitted outerwear garments produced on the "cut-and-sew" principle mainly due to its high extensibility and the fact that the seam encloses the raw or cut edges of the two fabrics in a tube or sheath of stitches preventing them from ravelling out during wear[54]. However, its bulkiness often makes it unsuitable for close-fitting garments[54].

Outerwear manufacturers who work with knits weighing from 135 to 200 g/m^2 principally made on 28 gauge interlock equipment use overedge machines which produce stitch types in the 500 category, often using the stitch type 504 (a three-thread overlock)[49]. In cases where the edge strength of the knit goods being sewn is low and a wider seam allowance is desired, a stitch type 514 two-needle overlock is sometimes used although grinning of the seam is a possibility. In all, there are 21 individual types in the overedge category (type 501 to 521), a class which is also referred to in the garment industry as *merrow, overlock* or *superlock*. Five other stitch groups could also conceivably be applied to the seaming of sweaters and other knitted outerwear and underwear fabrics[49]. These are chainstitch type 100, handstitch type 200, lockstitch type 300, doublelocked stitch type 400 and single-thread lockstitch type 700[49] (see Table IV). For sweaters, the overedging stitch is generally best, the type 504 being the most common[40]. Safety stitches, which are really combinations of overedge stitches and double-lock stitches, are sometimes required, the most popular being type 514 and 516. Both possess good elasticity as well as covering power and durability[40]. The following table (Table V) gives some guidelines for safety stitch seaming[57].

An important stitch type in the sewing of athletic shorts and other similar underwear garments is the *flat seam stitch*, the type 607 (a six-thread stitch) being particularly good[40]. The class of sewing machine most highly recommended for the construction of body conscious lingerie and other at-home wear made from lightweight, drapeable knitgoods, is the flat seamer[49]. This category, which includes seven types of stitches (types 601 to 607) appears to be equally appropriate to the seaming of dresses and of men's and women's tops made of todays softer, lighter and more drapeable knitted fabrics[49]. The type 605 flat seam (five-thread construction) is the most widely used for the making-up of underwear, other intimate apparel and loungewear[49].

The *linking* machine is used in the knitting industry where loop-to-loop or loop-to-selvedge joins are required[54]. The linked seam has the needle thread passing through each individual loop of the knitted fabric being joined.

For knitted fabrics it is advisable to make greater use of overedge and chainstitch equipment and differential and compound feeding machines[32]. All working surfaces and trucks should be smooth to reduce snags. Too high number of stitches/per cm can contribute to puckering whereas too few can weaken the seam. The following is suggested as a guide[32]:

Seaming (Inside): 3,5 to 3,9 stitches/cm

Seaming (Outside and inside stress seams): 4,3 to 4,7 stitches/cm

Overedge: 1,6 to 2,4 stitches/cm

Serging: 3,1 to 3,5 stitches/cm

Blindstitch: 1,6 stitches/cm .

TABLE V

Operation	THREADS		S.P.I.	NEEDLE SIZE	
	Needles	Under*	(/cm)	Singer	Metric
Artisan Wear (Heavy)	Drima-T80	Drima-T80 or Drima-T120	12 (4,7)	14	90
Blouses	Drima-T120 or Koban 120	Gral 200	12 (4,7)	12	80
Corsetry (Swimwear)	Koban 75	Aptan Seam Bulked Nylon Covering Thread 80	12/14 (4,7/5,5)	12/14	80/90
*Lingerie	Drima-T120	Drima-T180 or Gral 200	12 (4,7)	12	80
Overalls (Lightweight)	Drima-T120	Drima-T120	12 (4,7)	14	90
Pyjamas/ Shirts	Drima-T120 or Koban 120	Drima-T180 or Gral 200	12/14 (4,7/5,5)	12/14	80/90
Linings	Drima-T120	Drima-T180	10/12 (3,9/4,7)	12/14	80/90
*Dresses (Knitted)	Drima-T120	Drima-T180 Gral 200	12/14 (4,7/5,5)	11	75

*Aptan Bulked Nylon Seam Covering can be substituted where a soft finish is desirable

As a rule, a stitch length of 5,5 to 6,3 stitches/cm is satisfactory for most knitted fabrics[40]. It may be best, however, to experiment with different stitch densities depending upon the fabric mass and resilience[40]. Stitch densities of 3,1 to 5,5 stitches/cm for chainstitch and overlock stitch are feasible for 28 gauge knitted fabrics although it is preferable to stay within the range 3,9 to 4,3 stitches/cm[49].

In four-and five-thread safety stitch machines, 4 stitches/cm (10 stitches/inch) are sufficient, while double chainstitch requires 5,5 stitches/cm (14 stitches/inch) and lockstitch 6,5 stitches/cm (16 stitches/inch). These can be used as a guide but the seam must always be tested for cracking[31]. Perivale-Güntermann state that although single needle 3-thread overlock machines are suitable for fine gauge fabrics ranging from 7 needles/inch upwards, coarser gauge fabrics need twin-needle 4-thread overlock (stitch types 512 and 514) which should be set at approximately 4,7 stitches/cm[58]. Higher stitch densities could give an undulating stretched look to the seam whilst fewer stitches will produce seams with lower holding power and insufficient extensibility. Good width of bight is essential. Knitted tape should be inserted in the underarm and shoulder seams to improve strength at these points. The smallest ball-point needles consistent with fabric mass are generally recommended. For knitwear, the sewing thread should have adequate extension at break, hard wearing properties and good dimensional stability[58].

4.1 Seam Cracking

When a sewing thread breaks at one or more points along its length it is termed "seam cracking"[54]. This is one of the chronic problems facing the garment industry, particularly in knitted fabrics[59]. It occurs because the nature of seam construction, stitch formation and thread used in making the seam often restricts the stretch of the cloth. The problem is compounded by the trend towards tighter fitting garments. The problem of *seam cracking* can be avoided by proper selection of stitch, thread and seam construction. The following measures should prove useful[59].

(a) *Selection of stitches and seams:*

Overedge and safety stitches are best for all joining seams in knitted garments. Sewing machines with differential feed can be set up to handle almost any knit cloth and to produce seams that have complete extensibility without cracking stitches. Stitch balance is essential. The use of chainstitch will also reduce the tendency of seams to "crack". Certain cases (e.g. pockets, collars and cuffs, plackets and other trim and decorative stitching seams) require lockstitch seams for proper appearance or seam security. If the fabric in the construction is allowed to stretch under load, the lockstitch seam with its limited extensibility will quickly apply the full stitching load on the seam itself and the chances are that the thread will break. In such cases it is important to limit the stretch of the seam by structural components already a part of the garment (e.g. woven or nonwoven interfacing, zipper tape, etc.) or by insertion of a tape in the seam to control extensibility (i.e. to share the load without stretching unduly in the process)[59].

(b) *Control of foot pressure:*

Presser-foot pressure must be as light as possible with consistent feeding. Excessive pressure tends to impede the movement of the top layer of fabric and invites the possibility of damage by the teeth of the feed dog[58].

(c) *Needle and thread size:*

Needles of the smallest possible size should be used. This requires a thread with a smaller diameter, smooth construction, heat resistant finish, recoverable elongation, good extensibility and consistant mechanical properties[59]. Seam inspection is essential, particularly in the case of chain stitching where skipped stitches would result in seam failure and run-back. Small needles with thin or fine ball-point should reduce the possibility of needle hole damage[59].

4.2 Seam Pucker

Seam pucker is caused by a distortion of the sewn fabric either during sewing or at a later stage and it may be inherent in certain types of fabric (e.g. close constructions such as rainwear or nylon overall fabrics) since the fabric along the length of the seam is extended relative to the fabric adjacent to the seam, producing a buckling effect[4]. Fabric, fibre, mass, construction, finish, etc. can all play a rôle in determining puckering[60]. There are basically four main types of pucker, viz. *feeding* pucker, *tension* pucker, *inherent* pucker and *thread shrinkage* pucker[60]. Pucker is one of the problems associated with lap felling on fine fabrics and even in general seaming has become especially troublesome with resin coated and synthetic fabrics[57]. Elsewhere[2] it is stated that seam puckering can be due to:

1. Structural jamming
2. Differential feeding
3. Wrong seam construction and sewing procedures
4. Inadequate needle and thread sizes.

Seam pucker is rarely encountered in knitted fabrics due to the relatively high extensibility and compressibility of such structures[54].

Feeding pucker is caused by the slippage of one ply of material against the other during sewing and is more common with hard, slick-faced, lighter fabrics and the limitations of most simple drop feed mechanisms to transport two or more plies of material uniformly throughout the seam length[60]. Generally, the feed dog tends to feed in the under ply whereas the presser-foot retards the upper ply, a condition further aggravated by "flagging", i.e. the rise and fall of the material during feeding[60]. The importance of correct feeding as far as seam puckering is concerned has also been reported elsewhere[40].

Feeding pucker occurs mainly with *drop* feed which remains widely used, although a wholly satisfactory solution has not been found for differential feed either[61]. Negative differential feeds give better results than the positive versions. In general, however, the outcome mainly depends upon the operator's skill[61]. The sewing direction is of great importance since, in most cases, the surface roughness of the fabric differs in the warp and in the weft, which causes friction between the plies. In practice, considerably less feed pucker occurs when sewing in the direction with higher friction (e.g. in the weft direction where interlocking of the two plies occurs). The interlocking of the upper and lower plies ensures a uniform feed of both plies. Relative shifting of the two plies during sewing, therefore, always causes a tension in the seam and thus seam puckering[61].

It is recommended that a fine sharp-toothed feed-dog be used and that it be set as low as possible[60]. To reduce slipping between fabric layers, non-differential feed dogs can be adjusted so that the front portion of the feed dog is lower than the rear[62]. Furthermore, the presser-foot pressure should be reduced to a minimum compatible with seam transportation. Finally, the operator can also use a "nip and run" technique of sewing which involves the operator nipping the seam (fabrics) on both sides of the presser foot and then allowing the firmly gripped seam to move through the sewing machine in synchronisation with the feeding action. The seam must not be pulled through the machine or retarded in any way[60]. Distortion of the plies during sewing always causes seam tension leading to pucker. Where possible, sewing machines with top and bottom or intermittent roller feed should be used. If only normal bottom feed is available, it is recommended that the material should be pulled gently from behind the presser foot, taking care not to stretch the fabric[63].

One system for stopping puckering (called Puckering Stop or Kräusel Stop) consists of a special self-adhesive film which is easily attached to all sewing machines[61]. Because of its adhesive strength it has a favourable braking effect on all materials. The bottom ply is delayed to such an extent that unwanted displacement caused by the feed system is prevented, even on very smooth materials. Stitch length is important for neat seams and 4-5 stitches/cm are recommended when using "Kräusel Stop". The most suitable stitch length depends upon the elasticity of the material. Coarse tooth feeders (5 — 7 teeth/cm) are recommended for "Kräusel Stop" and correct foot pressures are important[61].

Tight-sewing tensions are one of the main reasons for seam pucker[60]. Threads stretch during sewing, and puckering results when they relax afterwards[60]. In another article, it is stated[4] that wrong sewing conditions such as too high a thread tension or presser-foot pressure, can also cause pucker. In either case there is a tendency for the fabric in the seam to be compressed and shortened relative to the relaxed fabric and for fabric distortion to occur near the seam[4]. The pucker may only manifest itself at a later stage as the thread may only relax slowly after it has been stretched during sewing[4].

Tension pucker not only has a negative effect on the seam appearance but also on its strength. It is most likely to occur when sewing in the warp direction[61]. The main causes are the feed system and sewing tension, while the construction and elasticity of the fabric determine the degree of puckering. In one study[64] it was concluded that puckering was mainly related to yarn tension, it increasing with increasing yarn tension. It also increased with an increase in sewing speed and with a decrease in stitch length[64]. It is possible to reduce tension puckering considerably or, depending on the type of material, to prevent it completely, if the work piece can be stretched slightly while sewing[61]. Once the stitch is completed the work piece returns to its original state, with the seam relaxing. Puckering is then reduced because there is more spare thread in the seam[61].

To reduce the risk of puckering the lowest possible thread tension, consistent with proper stitch quality[32,65], as well as the lowest presser-foot pressure, should be used[32]. As a general guide for bobbin thread tension, especially for synthetics, the bobbin should slowly glide down when held by the thread[63]. The larger the stitch the smaller the risk of pucker, while 4-5 stitches/cm are recommended; stitch length should never fall below 2 mm for closing seams.

Meters and other devices are available to check thread tension and foot pressure to establish the appropriate conditions for a given fabric and to maintain these. Some of the older machines may be correctly set at the start of the day but may become unbalanced as the day progresses. J & P Coats produces and markets an instrument (Coats Tension/Presser Meter) which is regarded as an invaluable aid in instances where machine maladjustment is causing puckering[66]. The maximum needle thread tension in each cycle directly affects the quality of the stitching, if it is too low the seam will "grin", if it is too high the seam will pucker[66]. Standard levels can be established for various fabrics and such meters can also be used to ensure that both needles of twin-needle machines are at identical tensions. Constant checks throughout the day may be essential for older types of machines. The Tension/Presser meter can also be used in conjunction with the Kirby Lester TA7 Thread Tension Analyser which is invaluable for determining the stitch performance on long runs, particularly when using automatic stitchers where there is no operator to keep a close watch on the quality of each batch of thread. The TA7 produces a graph of the stitch tensions on the machine[58,67].

Inherent pucker depends upon the physical properties of the fibre, fabric density, finish, etc. On being disturbed by needle perforations and consequent thread bulk, the yarns in the fabric resist the resultant displacement and strive to re-occupy their previous positions[60]. As this is no longer possible due to the presence of the sewing thread, they shape themselves around every stitch exerting pressure which results in seam distortion[60]. This distortion of the natural line of warp and weft threads, causes them to shorten lengthwise and the resultant pucker is termed "inherent". The relation of needle thickness, thread thickness, number of stitches/cm now becomes obvious and it follows that the finer the needle/thread and the lower the stitch density (stitches/cm) the lower the inherent pucker will be. Needle pucker is mainly a deformation of the fabric yarns and is particularly difficult to avoid in dense, closely woven cloths, more particularly so if they have been resin treated[68].

Over-large needles can cause seam pucker even when used without thread[63]. The finest possible needle, with a slightly rounded point, has been found to give the best results. The clearance between needle bore and diameter must be restricted so as to avoid material stretch. Also the slit in the presser foot should be as small as possible[63]. During sewing, the needle has to make space for the thread(s). Because in most fabrics, the warp density is higher than that of the weft, the needle must displace more warp than weft yarn and can cause a shortening of the warp yarns and a contraction of the fabric along the stitch line. Sewing in the weft direction is generally less problematic since the weft gives way to the needle more easily and each warp yarn is displaced only once. Entirely satisfactory results are usually obtained when sewing diagonally and, wherever possible, the seam should not follow the warp but should deviate by from 10 to 20°[63]. Darts and slightly slanted seams also help to avoid pucker in closely woven cloths[69]. Elsewhere it has also been suggested[70] that seams running parallel to the weft are generally less inclined to *pucker* than those running parallel to the warp and seams on the bias are even less likely to pucker. Chainstitch seams are less likely to pucker than lockstitch seams since the interlooping of needle and underthreads takes place outside the fabric[63,70].

Threads contribute to seam pucker in two ways, 1) by being stretched during sewing and contracting afterwards and 2) by causing insufficient space between the threads of the fabric[71]. The thread size and type are also of major importance[63]. The coarser thread takes up too much space within the fabric and consequently displaces more fabric yarns than a finer thread[63]. When using a coarse sewing thread a chainstitch (e.g. 401) often gives less puckering than a type 301 or lockstitch, since it places only two threads as opposed to four in each needle hole[71]. Visible seams, such as run-stitching, should be avoided and the safety-stitch is apparently the most suitable[63].

Threads with greater shrinkage than the fabric being stretched can cause *thread shrinkage pucker* [70]. Conventional threads absorb moisture, swell, thicken and shorten lengthwise leading to seam pucker[60]. To minimise *thread shrinkage pucker* it is recommended that low tensions be used and that dimensionally stable sewing threads be used. Suitably stabilised synthetic sewing threads are generally preferred when thread shrinkage pucker presents a problem and low shrinkage (0 to 1%) synthetic threads are now produced to this end[60]. Thread shrinkage relative to the fabric may also occur during laundering leading to pucker[4].

Waviness, as opposed to *puckering,* generally occurs with soft, stretchy fabrics and also with bias cut woven fabrics. The pressure exercised by the presser foot against the needle plate causes the fabric to spread and when the fabric returns to its normal size, waviness occurs[62]. To reduce *waviness* the feed dog is adjusted so that its rear portion is lower than the front. Among all the methods described, *differential feed* (positive and negative) is the one which is the most effective in reducing or eliminating *puckering* and *waviness.* Differential feeding is obtained by having two feed dogs with independent movement. Positive differential feed means that the feed dog in front of the needle makes a longer movement than the one at the rear. Negative differential feed means that the feed dog in front of the needle has a shorter motion than the feed dog behind the needle. The latter is also effective when puckering is caused by thread elasticity (stretch) and subsequent contraction. Thread take-ups can also reduce puckering[62].

4.2.1 Further Hints on How to Prevent or Reduce Puckering

The overlock stitch 504 generally presents the least amount of problems as far as puckering is concerned when sewing overlock and safety stitch seams[72]. Elsewhere it is also claimed[57] that danger of puckering is reduced by use of the safety stitch.

Needle size relative to fabric and throat hole is important if pucker is to be kept to a minimum[72]. The needle hole should be no larger than necessary to provide minimum clearance around the needle. For certain stitches (e.g. 401) the needle hole should not be too long. Where possible, the needle should be double grooved (i.e. back and front), reducing the possibility of the material pinching the sewing thread[72].

The use of Teflon foot sole and Teflon surfaced throat plate may also be desirable[25]. It may also be necessary, in extreme cases, to cut fabrics to a minimum of a 5° bias[25]. Lubrication of the fabric/needle area is claimed to reduce pucker as well as needle heating[48].

Puckering may be reduced by a relatively finer tooth in the feed dog since this leads to less slippage of one ply relative to the other[72]. A diamond shape tooth can sometimes also be used to advantage. Approximately 7 teeth/cm (18 teeth/inch) is recommended for troublesome materials. A stretching differential feed greatly reduces the risk of puckering, the material actually being stretched while it is under the foot and while the needle is penetrating it[72].

The feed slots in the *throat plate* should be no longer than necessary for the stitch length being used[72]. Although in most cases on an overlock and safety stitch machine the feed cannot be timed independently of the needle bar, it should be set so that a full tooth shows above the throat plate and as level as possible as a starting point. The *presser foot* should be neither too wide, too narrow, too long or too short and should just cover the feed area. The presser foot should match the fabric. It is also important to maintain a good sharp top and lower trimmer knife as well as a trimming edge set correctly to the needle hole piece tongue[72].

4.3 Seam slippage, strength and extension

When a seam opens and produces a gap between the two pieces of fabric, it is called *seam grin* [73], this being controlled by stitching tensions and stitch density. When the fabric on both sides of the stitching distorts and threads within the fabric slide away from the seam, it is called *seam slippage*. Seam slippage arises principally from the construction of the fabric[6,73] rather than the seam but it can be reduced by overlocking raw edges, by using more than one line of stitching and by increasing the number of stitches/cm[4,6]. Both fabric structure and finish affect the ease with which a seam can be sewn and the performance of the seam afterwards[4]. *Seam slippage* occurs predominantly on certain types of fabric, notably those containing continuous filament yarns with relatively few yarn interlacings (e.g. sateens). The few interlacings result in low inter-yarn frictional forces and under strain, the yarns can slip more easily resulting in an unsightly gap or even complete seam failure. Sewing seams at an angle to warp or weft can reduce seam slippage to some extent[4]. Two articles[74,75] deal with recommended methods for measuring seam slippage and a simple device for assessing seam slippage has been developed[76].

When a seam joining two fabrics is subjected to stress at right angles to its length, a point is ultimately reached where the seam fails by rupture, either a) of the sewing threads leaving the fabric intact (Type 1) or b) of the fabric leaving the sewing thread intact (Type 2). It is rare that both these occur simultaneously[54]. The breaking strength of a single-row lockstitch seam under Type 1 conditions can be calculated with a fair degree of accuracy by using the following equation[54]:

$$T = 2\,tn$$

where T is the breaking load of the seam (N/cm)

n = number of stitches per cm, and

t = *minimum knot* strength of sewing thread, measured after stitching into, and recovery from, a seam sewn in soft blotting paper[54]. For 2-thread chainstitch seams the above equation slightly underestimates the actual strength.

Bain discussed the prediction of lockstitch *seam strength* in woven fabrics. He advocates the use of the corrected minimum loop strength (CML) for predicting seam strength, although for most threads and fabrics, predictions could only be made by introducing at least one constant to account for fabric-thread-gauge-interactions. Although CML strengths have better results than average loop strengths, no general formula was found to fit all the threads or all the fabrics tested[5].

Seam efficiency has been defined[54] as: $\frac{\text{Seam breaking load}}{\text{Unseamed fabric breaking load}} \times 100$

and under Type 2 conditions optimum stitch rate = $\frac{\text{Fabric Sett (warp or weft)}}{6}$

where sett is expressed as threads/inch. When a seam is stretched under Type 2 conditions the opening load (load to cause the seam to "grin") is mainly dependent upon[54]:

(a) The stitch rate

(b) Weave structure

(c) Width of seam allowance

A seam efficiency of ≈ 70% is generally acceptable for woven, whereas it should be just below 100% for knitted fabrics[77]. Under type 2 conditions seam efficiencies greater than ~ 80% are not commercially feasable. Generally it is the minimum loop strength of a sewing thread that governs seam strength and not the mean tensile strength as determined on yarn taken directly from the bobbin (see Fig 6)[54 71].

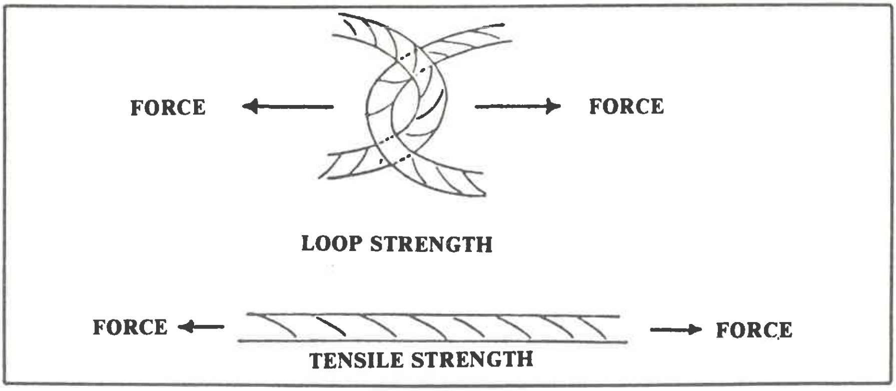


Fig 6 – Loop and tensile strength

In knitted fabrics, because of their stretch the thread often bears a fraction of the stress generated which means that finer and hence a cheaper thread can be used for knitted than for woven fabrics[71]. The *knot test* is regarded as an alternative to the loop test[54] and for minimum knot strength tests, 10 knots (see Fig. 7), can be tied at ≈ 2,5 cm intervals in a 46 cm length of yarn and the yarn is then strained until it breaks at the weakest knot. Best correlation is obtained, however, if thread is used which has already been sewn, into blotting paper for instance[54].

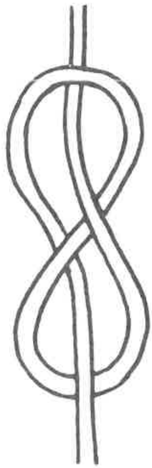


Fig 7 – Knot test

Blackwood and Chamberlain[54] describe various methods for testing sewing threads and seams. They concluded that the strength of seams in knitted fabrics under Type 1 condition can be calculated by means of the seam equations used for woven fabrics.

For knitted fabrics the equation becomes:

$T = 2\,tn\,F$

where F is a constant

= 0,92 for lockstitch seams

= 1,12 for 2-thread chainstitch seams,

and = 0,94 for 3-thread overlock seams[54].

For *three-thread overlock* seams under transverse load, the breaking load per loop at high stitch rates was less than that at lower rates[78]. A good correlation was found between the seam strength and the loop strength although the former was always lower than that predicted theoretically from the latter, probably due to assymmetry in the arms of the individual loops[78].

Increasing stitch density increases seam strength until *fabric* breakdown takes over from *thread* breakdown, although in woven fabrics a reduction in seam strength occurs at the high stitch densities due to seam damage[79]. This can generally be avoided in knitted fabrics. Loop strength is generally higher than the actual effective thread strength in the seam and certain corrections have to be applied to improve the agreement. The transverse strength and longitudinal extension of the lockstitch seam in knitted fabrics have been studied in some depth and it was found that minimum transverse seam strength/cm = stitches/cm x 2 (assymmetric loop strength). Furthermore, the maximum extension properties of the lockstitch seam are obtained at equal bobbin- and needle-thread lengths, with extension increasing with increasing stitch density and decreasing thread tensions. Thread extension contributes to seam extension by increasing the effective thread length[79]. The single-thread chainstitch transverse strength and longitudinal extension have been analysed, both theoretically and experimentally[80]. *Seam strength* was shown to depend upon stitch density and the minimum assymmetric loop strength of the sewing thread, whereas *seam extension* depended upon run-in-ratio and thread extensibility, subject to restrictions imposed by the finite thickness of the fabric in the seam[80].

Chainstitch and overlock seams are generally found to be stronger[46,81] and more elastic[46] than lockstitch seams and, within the limits of the fabric, if the stitch density is increased by 10%, the seam strength will increase proportionally by 10%. Table VI compares threads, seam strengths and needle sizes[81].

The seam strength of fabrics has also been studied by Shimazaki[82] and the effect of angle of bias and other related parameters on seam strength of woven fabrics has also been studied[83].

Perhaps the most important seam property required in knitted fabrics is *extensibility,* this being affected by thread elongation (extension) in addition to other factors. Sewing threads can be ranked in the following order of increasing extension[81]:

Cotton $<$ spun polyester $<$ corespun $<$ bulked nylon seam covering thread $<$ spun nylon linking thread.

TABLE VI

COMPARISON OF THREADS, STITCH STRENGTHS AND NEEDLE SIZES

Thread Type	Tkt. No.	Metric Size (Nm/dtex)	Stitch Strength (N/stitch)	Recommended Needle Size (Metric)
Mercerised Cotton	60	34/295	7,6	80
Mercerised Cotton	50	28/355	9,8	90
Mercerised Cotton	40	20/490	14,7	100
Spun Polyester:	180	52/191	10,7	70
Drima-T	120	34/295	15,6	80
Corespun: Kobat	120	40/250	10,2	80

The 3-thread overlock seam provides excellent extensibility although properly designed 2-thread chainstitch and lockstitch seams can also be satisfactory for knitted fabrics. From the point of *extensibility, stitch rate* is of primary importance[54], a high rate favouring extensibility and also minimising "gape".

Best elongation for *lockstitch* seams is obtained with balanced stitches[811]. To get the best from *chainstitch* seams, the ratio of needle to looper thread should normally be between 1 to 2 and 1 to 4. Highly extensible threads do not perform well as needle threads but if used as under threads particularly in the looper of a chainstitch, seam-covering or linking thread, can give a significant bonus in seam stretch without affecting sewability. In the *overlock* seams the limit of extension is set by the needle thread and a suitable synthetic thread should therefore be used in the needle. Stretch can be increased in any seam by increasing stitch density[81].

5. THE FABRIC

Most of the problems associated with sewing damage lie with the fabric[3]. Although serious needle cutting can occur in woven fabrics, its effect is often limited since the interlacement of the woven structure resists the spreading of the damage. With knitted fabrics the problem is far more severe since a severed yarn can lead to loops unravelling, laddering and spreading the damage[4]. Other articles have also stated that needle damage is mainly a problem with knitted fabric[3] but also with fine woven fabrics[3,12].

5.1 Fabric Sewability

Stitching damage is influenced by (i) structure and yarn settings in relation to the size of the needle (the denser the fabric the more likely it is to suffer sewing damage), (ii) fabric, fibre type, yarn twist and yarn extensibility, (iii) type of dyestuff and amounts of size, resin, softeners, lubricants, etc., (iv) fabric regain, (v) sewing machine factors (e.g. presser foot design and pressure)[14].

As a needle forces its way through a knitted fabric, the yarn may break partially or completely, producing a hole (sewing damage)[13]. The fabric yarn may break by it being stretched beyond its braking extension or by a hot needle melting or burning the yarn. Clearly, the size of the loop relative to that of the needle, as well as the ease with which yarn may be "robbed" from adjacent loops, will have a very important bearing on the chances of yarn breakage. So, too, will the elongation of the yarn in the fabric. Yarn-to-yarn friction, therefore, is very important as far as the mobility (ease of robbing) of the yarn within the fabric is concerned. This is where lubrication, fabric tightness, finishing, etc., can be of paramount importance[13].

The elasticity of knitted fabrics creates excellent wearing characteristics but at the same time very difficult sewing problems[45]. The choice of the type of sewing machine to be used for knitted fabrics entails three basic factors: 1) the fabric must not be damaged, 2) the seam must be elastic and 3) strong patterns must not be distorted due to fabric plies which have been shifted during the sewing period. The first requirement is to choose the lightest thread possible, the thinnest possible needle with appropriate point and also the proper stitch type and seam selection[45]. Table VII has been given as a guide for the sewing of knitted fabrics[84].

In one article[85] guidelines are set for cutting and sewing of *fine* double jersey fabrics. The main stitches to be used are lockstitch (304), overlock (504) and chainstitch (401). In sewing 22-28 gauge and 38-40 gauge double jersey fabrics, needles of size 9 (0,65 mm) or size 7 (0,6 mm) and size 7 or size 6 (0,55 mm) should be used, respectively. Polyester filament threads (133-167 dtex) are recommended as needle threads and textured polyester (or nylon) in 111 to 167 dtex as looper

TABLE VII
SEWING GUIDE FOR KNITTED FABRICS

Operation	LIGHT/MEDIUM FABRIC				MEDIUM/HEAVY FABRIC			
	Thread		Needle		Thread		Needle	
	Needle	Under	Singer	Metric	Needle	Under	Singer	Metric
General Sewing (lockstitch)	Koban 120 or Drima-T120	Koban 120 or Drima-T120	11/12	75/80	Koban 75 or Drima-T80	Koban 75 or Drima-T80	14/16	90/100
General Sewing (chainstitch)	Koban 120 or Drima-T120	Koban 120 or Drima-T120	11/12	75/80	Koban 75 or Drima-T80	Koban 120 or Drima-T120	14/16	90/100
Overlocking	Koban 120 or Drima-T120	Gral 200 or Aptan Bulked Nylon 80	11/12	75/80	Koban 75 or Drima-T80	Aptan Bulked Nylon 80	14/16	90/100
Buttonholing	Koban 120 or Drima-T120	Koban 120 or Drima-T120	14	90	Drima-T80	Drima-T80	16	100
Buttonsewing	Koban 120 or Drima-T120	Koban 120 or Drima-T120	14/16	90/100	Koban 75 or Drima-T80	Koban 75 or Drima-T80	16	100
Blind Stitching	Gral 200			75	Gral 200			80

thread[85]. The lockstitch seam is also widely used in making-up both single and double-jersey fabrics[79] but the overlock machine remains the foundation of the knitted outerwear sewing operation[86]. For the two-thread chainstitch in knitted fabrics, maximum seam extension requires a high stitch density together with a looper-thread/needle-thread length ratio of the order of 3[87].

Sewing of sueded and knitted apparel should always be carried out with a ballpoint needle[88], using a safety stitch machine (combination of Type 401 double locked stitch and either a Type 503 or 504 overedging stitch). The result is a Type 514 or 515 stitch depending upon the type of overedging stitch employed. The number of stitches/cm should be from approximately 3,5 to 4,7. Too short a stitch length should be avoided[88].

It is claimed that, in general, 100% textured set polyester filament double knit fabrics are the most resistant to needle cutting while 100% spun polyester or spun polyester/wool double knit fabrics are the most prone to this defect[11,89].

Fabrics knitted from continuous filament yarns are less liable to break during sewing than those knitted from staple-fibre yarns mainly due to their frictional characteristics[8]. Furumatsu and Yanagi[90] studied the sewing of knitted polyester fabrics. They recommended 7 stitches/cm as a general rule, although 3 stitches/cm produce excellent seam appearance while 5 stitches/cm are recommended for high abrasive strength. It was found that stitching in the coursewise direction results in excellent appearance and higher tensile strength, whilst stitching in the direction of the wales is recommended for higher bursting and flat abrasion strength. Zig-zag stitching will lead to an increase in bursting strength whilst straight stitching is recommended to counter flat abrasion[90].

The seam type SSa-1, sewn on a single needle lockstitch machine (stitch type 301) is often used on wool double jersey cloth although a double "locked" chainstitch type 401 may also be used in certain cases[91]. Provided reasonable precautions are taken, sewing damage is normally no problem in all-wool double jersey fabrics, although the finer the knitting machine, the greater the likelihood of such damage. As far as sewing damage in wool knitted fabrics is concerned, needle size and dry cleaning are the most important factors, with sewing speed and dyestuff also important. Metal dyestuffs appear to cause three times as many faults as chrome or reactive dyes and an increase in sewing speed from 3 600 stitches/min to 4 600 stitches/min caused the fault rate to double on dry cleaned fabric. To minimise sewing damage, fusible interlinings are preferred to conventional interlinings which have to be pad stitched.

For double jersey fabrics in wool, a size 12 ball-point needle and 4,5 stitches/cm are recommended. Seam pucker is rarely a problem with wool double jersey fabrics, although it is advisable to ensure the correct adjustments of thread tensions and presser foot pressure. After adjustment of presser foot pressure (usually so that, with the feed dogs below the throat plate, the fabrics can be moved backwards and forwards smoothly), the feeding mechanism is adjusted which is usually at an optimum when the feed dogs are adjusted to their maximum height, i.e. to have half to three-quarters of the teeth showing above the feed plate[91].

Puckering can occur in fine knitted fabrics and to reduce this it is recommended that the thread tension and presser foot pressure be reduced and low height and fine teeth (7,9-8,7 teeth/cm) be employed for the feed dog. Furthermore, the hole of the throat plate could be reduced and the edges could be rounded[85]. Care must be taken to avoid marking the cloth during sewing and to this end feed dogs with approximately 4,7 to 5,5 teeth/cm should be used[88]. The tilt of the feed dogs should be slightly higher on the back than the front to produce more feed from the needle[88]. For single jersey fabrics it is always best that the number of teeth per cm in the feed dogs be at the fine end rather than at the coarse end of the scale with the teeth set in such a manner so as to expose their minimum height, just enough to grip the fabric and feed it properly[40].

For knitted fabric, the drop feed can be supplemented with the variable top feed[45]. The differential bottom feed assures maximum elasticity in seam construction. Differential bottom and variable top feed systems can be combined which allows for[45]:

1. Even feeding of both top and bottom ply
2. Working fullness into the top ply only
3. Working fullness into the bottom ply only
4. Stretching both plies
5. Alternating the above to create complex seams.

Lightly knitted fabrics, weak yarns and fibres with high frictional characteristics are particularly susceptible to sewing damage problems[92]. Finishing, particularly solvent scouring, can radically affect the sewability of a fabric[92]. Paraffin wax emulsions have traditionally been used to lubricate cotton sewing threads, although for synthetic threads and for high speed sewing, silicone wax emulsions are more efficient[93].

Needle damage is attributed largely to excessive yarn or filament extension although sometimes the yarn can be fractured by the direct impact of the needle when sewing a number of fabric layers, the sewing damage increasing with an increase in the number of fabric layers, with more damage being suffered by the bottom layer than by the top layer[14].

It appears that fabric knitted on 24 gauge machines is probably more prone to needle damage than that knitted on 18 gauge machines[11]. Very often damage is more severe when the seam is on the bias than when it follows either the courses or wales[15]. Furthermore, when measuring needle penetration forces while sewing parallel to the wales, the values were found to lie very scattered[15]. Reduced sewing speed is also conducive to better sewing performance, since more time is available for the fabric to accommodate the needle[12]. Fabric bursting, which is particularly prevalent with knitted fabrics, is largely unaffected by sewing speed[94] although elsewhere it is claimed that for knitted fabrics, *needle cutting* increases with increasing sewing speed[95]. Fewer stitches per unit length is obviously associated with fewer needle penetrations, reducing the probability of needle cutting. Selecting the stitch length so that the needle penetrates the fabric between courses or wales or between ends and picks can also reduce the incidence of needle cutting[29].

The frictional properties of the fabric have a direct bearing on needle heating. Highest friction is generated by densely woven fabrics comprising continuous multi-filament synthetic yarns[26]. Heat generated by friction between needle and fibres in the material, especially in fire-resistant materials, can damage seams and fabrics. It can also cause thread breaks and damage the needle by drawing its temper and weakening it so that it breaks[16]. Fabric finish (or dye) can be a prime factor in affecting needle heating and sewing damage in thermoplastic fibre fabrics[114]. Furthermore,for cotton drill fabric, needle temperature increases as the fat and wax content in the fabric decreases. Heavier fabrics generally generate higher temperatures and newer wash-and-wear and permanent-press finishes tend to generate more heat than the usual softening and lubricating finishes mainly because they are applied in such large quantities[14]. Acrylic knitted fabrics are regarded as particularly susceptible to frictional heating and fusing in stitching and an increase in fabric mass increases needle temperature linearly. Fabric finish and treatment can have a noticeable effect on needle temperature and solvent scouring, which removes nearly all lubricants, can have a particularly severe effect on needle temperature. For cotton, the main effect of fabric finishing is due to the removal of the cotton wax[34]. Lower needle temperatures have been recorded for all-cotton than for 65/35 polyester/cotton fabrics[49].

When stitching at 6 000 stitches/min on a strong and closely woven material an ordinary needle reaches 400°C or even higher[14] which can affect the hardness of the needle. Even at 3 000 stitches/min on a medium heavy fabric needle temperatures of 250° C can be reached which is sufficient to melt synthetic fibres. Natural fibres can withstand higher temperatures but if resin has been applied to them, this can melt like the synthetic fibres. Only at temperatures above about 350° C is cotton affected by needle heating[71].

Sometimes knitted fabrics generate more heat when sewn in one direction along the wales than when sewn in the opposite direction along the wales, the reason for this not being clear. As a general "rule of thumb" the needle temperature will approximately double when the number of the fabric plies are trebled[34].

For knitted fabrics, test sewings should be at a diagonal to the wales and not parallel to them, with sewing generally best when done in the direction the fabric was knitted. Direction of sewing also plays a rôle in warp-knitted fabric[48].

In summary, therefore, stitching damage can be reduced by taking the following steps[14]:

1. Reduce needle size
2. Do not use a blunt or damaged needle
3. For tightly twisted yarn use a ball-point needle and for loosely twisted yarn use a sharp needle
4. Lubricate the fabric
5. For knitted fabric do not exceed speeds of 3 600 to 4 000 stitches/min
6. Maintain the relative humidity in the store and sewing room at around 65% RH.

The making-up of knitted garments has been covered in a recent two-part article[96]. The making-up of wool fabrics has been dealt with in great detail in another article[97], the making-up properties being related to the fabric mechanical properties. Wignall[98] has reviewed very briefly the aids to sewing and seaming of knitted garments while Lewis[99] has reviewed the factors involved in the development of sewing damage in all-wool and wool/synthetic double jersey fabrics. Recently[100] a list and description of garment assembly equipment and sewing threads available for knitted goods has been published. The rôle of machine variables in the sewing damage of knitted fabrics is studied in some detail by Hurt and Tyler[30].

5.2 Fabric lubrication and finish

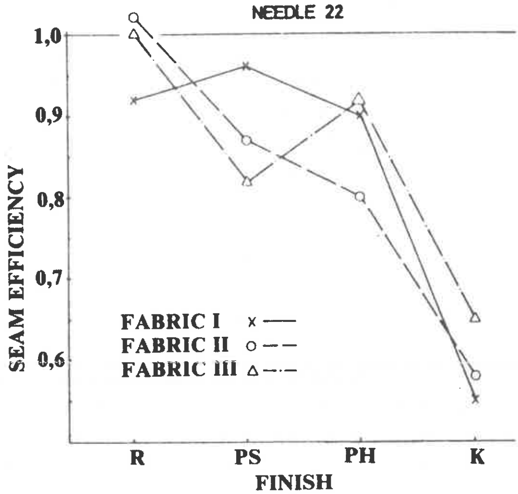
Sewing damage is conveniently classified into two classes viz. 1) that caused by excessive needle heat and 2) that due to mechanical damage, the latter being more frequently encountered and also more noticeable and troublesome[9]. The latter is mainly a function of needle size and fabric lubricant content[2]. Fabric lubrication can reduce both mechanical damage and that due to needle heat (i.e. fusing)[101] but extra lubrication of the sewing thread has little effect on sewing damage[3].

As the penetration of the needle through knitted fabrics depends upon the penetrated loop expanding and borrowing (robbing) yarn from adjacent loops, yarn and fabric lubrication is of prime importance[4]. This determines the yarn-to-yarn friction in the knitted fabric and if it is too high, the yarns cannot easily slide over each other when the needle penetrates the fabric, thereby increasing the probability of the yarn rupturing[94]. High yarn-to-yarn friction also increases the heat generated during sewing and the possibility of fusion[94].

The importance of an effective and suitable lubricant on the fabric to prevent sewing damage has been reported in a number of articles[8,9,11,29]. Of all the problems of seam damage submitted to Hatra for investigation, the vast majority were associated with fabrics having a low lubricant content[9,28]. Even the use of finer sewing needles (e.g. substituting a No. 12 for a No. 14) and use of a ball-point needle and other modifications do not always entirely eliminate sewing damage (needle cutting) on *unlubricated* double knit cloths[11]. Therefore, where at all feasible the fabric should be finished with a suitable sewing lubricant[23]. The degree of knitting yarn lubrication has a marked effect on sewability and so has the diameter of the sewing needle[102]. It has also been stated elsewhere[10] that the addition of lubricant ($\simeq$ 1%), the use of finer needles and the use of ball-point needles can minimize sewing damage in knitted fabric. The effect of different liquid yarn lubricants and levels on sewability of knitted fabrics was reported by Braun *et al*[103]. Suggested lubricant add-on for difficult knitted fabrics may be as high as 2 to 3%[31].

Scouring, bleaching and softening of interlock fabrics in cotton and cotton/rayon were all found to increase their susceptibility to sewing damage mainly due to a decrease in their extension at break properties[104]. Fig 8 illustrates the effect of various finishing processes on sewing damage in cotton interlock fabrics[13].

Setting can also increase the forces resisting yarn movement, leading to poorer sewability[13]. Treatments which increase yarn stiffness and inter-yarn frictional forces (i.e. reduce yarn mobility) will adversely



(I = combed cotton yarn; II and III = cotton-rayon-mixed yarns;
R = grey; PS = scoured; PH = softened after bleaching;
K = scoured after soften finishing)

Fig 8 – Sewing damage in interlock fabrics I, II and III finished in different ways [13]

affect sewability[13]. It is also important that the fabric be washed properly after printing since residual printing paste can stick the yarns together, resulting in problems during sewing[31].

In one study[105] the different factors affecting needle temperature were extensively investigated, a thermocouple being attached to the needle. Fabric lubricant and softener were found to be major factors in determining needle heat and temperature, although the lubricating action of certain softeners may be destroyed under severe conditions, adequate levels of softener being essential[105].

Dry-cleaning (or solvent processing) of fabric can reduce the natural lubricants and oils to such an extent that seaming damage becomes a real problem. If a suitable additive (lubricant, softener, etc.) is applied after dry-cleaning (or dyeing), however, sewing damage is generally eliminated[8,9,10]. It has been stated[9] that all softeners are good sewing lubricants and so are paraffin wax and lanolin. In fact, the paraffin waxes commonly applied to hosiery yarns during winding also act as effective sewing lubricants provided they are not removed during finishing. For wool and wool-blend fabrics, paraffin wax lubricants with melting points of 60 to 65°C provide good protection against needle damage[14]. Sewability damage has been found to be inversely related to the percentage lanolin content on worsted Punto-di-Roma fabrics[106]. Elsewhere[103] it has also been reported that waxing of yarns prior to knitting can improve the fabric sewability significantly.

Fabric softeners such as quarternary ammonium salts, silicones and polyethylene emulsions can be used on *fabrics* to improve their sewability[21], however, not all softeners give optimum sewability[107]. Furthermore, applying a softener, although reducing needle heat and sewing damage can aggravate laddering in a knitted structure because of a reduction in the inter-yarn frictional forces. Paraffin wax is an excellent lubricant and less likely to promote laddering[108]. It is important[11] when selecting a suitable lubricant that one is chosen which does not adversely affect fabric handle and which does not produce dye crocking or bleeding or affect the colour of the fabric. Too much of an incorrect lubricant can quite easily lead to the above problems. It is stated, however, that crocking can generally be avoided by using a cationic dyeable polyester instead of a disperse dyeable polyester. Dow Chemicals Emulsion 104, applied at a 1,5% level, is claimed to be a highly satisfactory lubricant for polyester. So, too, is ®Laurelsolv RL, ®Sol-Terg 3940 and ®Stantex 736 for applying from a solvent medium after a solvent scour[11]. A small amount of ®Alcolube SCA (Allied Colloids) improves sewability and also fabric handle[3]. Lubricants to improve the sewability of polyester double jersey fabrics are listed below[11].

Aqueous System

Dow Chemicals Emulsion 104

Du Pont's Avitex NA and ®Methacrol NA

Sandoz's ®Ceranine PNS

Nopco Chemicals CPS and 668

Standard Chemicals 612

Solvent System

®Laurelsolv RL

Berg Laboratories ®Sol-Terg 3940

Standard Chemicals ®Stantex 736

The following lubricants can be used for knitted fabrics containing staple polyester (Terylene), wool and nylon, application being from aqueous media[110]:

®Alcolube SCA (Allied Colloids), ®Atolex PFC (Standard Chemicals)

®Brandsyn PC 12 (Hickson and Welsh)

®Atolex NSL (Standard Chemicals) is regarded as suitable for solvent application[110].

®Cirrasoft is also claimed to reduce needle cutting significantly[111].

Schmetz makes unusual recommendations for stitching difficult fabrics such as elastic. For example, powdering the fabric with talcum, moistening it with water (with anti-rust solvent) and the addition of soap, all in an attempt to reduce friction[26]. Smearing the fabric with dry soap or spraying it with a silicone aerosol (such as produced by James Briggs of Manchester) are other suggestions. Spraying lubricant ahead of the sewing line can also sometimes work[3], although the lubricants are usually not as effective while wet.

Often fabric producers modify fabric construction or surface finish to improve handle and drape without carefully investigating the effects of these changes on sewability. The fabric supplier has the responsibility to alert the apparel manufacturer to the possibility that a softer handle due to some lubricant or a more open fabric construction can result in weak seams and/or seam slippage[1]. On the other hand, the use of a scroopy dry or hand building finish or a densely constructed fabric can result in excessive needle friction (and heat), fused crusts with thermoplastic fibres or yarn cutting on densely constructed cloths. It is, however, the ultimate responsibility of the apparel manufacturer to pre-test new fabrics so as to determine optimum needle size, needle shape, surface property and thread and seam design[1]. Pre-testing of new fabrics, by sewing the major seams under conventional conditions, is often essential[1].

6. SEWING THREADS

6.1 Sewing thread requirements

From the earliest times *silk* has been used for sewing threads and so, too, have linen and cotton[112].

Typical criteria of the quality of a sewing thread are its sewability and its durability in the seam[112] but often good sewability and good performance in the seam are not synonymous. An assessment of the relative importance of the properties of sewing threads has been made by means of a questionnaire and computer analysis of the results[113]. The properties were divided into four groups: (1) factors affecting the *sewing* process (stiffness, smoothness, uniformity, abrasion resistance, irregularity of elongation, cleanliness and twist direction); (2) factors affecting the *quality* of the sewn article (breaking load, variation in fineness, irregularity of breaking load, elongation and colourfastness); (3) *aesthetic* factors (uniformity of dyeing, appearance, quality, range of shades, correspondence of colour with shade card and whiteness); and (4) *techno-economic* factors. The computer analysis revealed that the most important properties are those in groups (1) and (2) and that producers and consumers were in agreement. It is concluded that, in the manufacture of sewing threads, it is essential to improve smoothness without reduction in breaking load, e.g. by finishing, singeing or mercerising, and that a slight increase in cost would be acceptable. Attention is also drawn to the thread fineness which, in the analysis of data from the manufacturers, is shown to be subject to significant variation[113].

Rhodes[68] states that the thread in a lockstitch seam of 4 stitches/cm passes through the needle's eye 38 times before being set into the fabric and the speed of the thread can be as high as 160 km/hr. It must, therefore, have great abrasion resistance and it must also have a minimal tendency to stretch under tension and relax at a later time[4]. Requirements of a good thread are said[114] to be:

1. Uniform diameter
2. Surface lubricity (low friction)
3. Suppleness (ease of loop forming)
4. Low elongation (gives less critical tension, etc.)
5. Torque free (balanced twist)
6. Low linting characteristics
7. Resistance to needle heat (low heat generation as well as good heat resistance).

The following factors contribute to the durability of a sewing thread[114].

1. Seam strength (loop strength)
2. Abrasion resistance
3. High elasticity
4. Shrink resistance
5. Minimum diameter
6. Colour fastness

High elasticity is important in a sewing thread because it helps determine the degree of stress or stretch a seam can be subjected to without rupture and quick recovery is necessary to maintain the seam appearance[114]. For good performance at the sewing machine, moderate to low extension at break is normally required for a sewing thread[115]. *Shrink resistance* means that the thread must remain stable during laundering and pressing so as to avoid pucker[114,115]. They should also be stable to finishing and laundering processes which will be applied to the fabric[12]. *Minimum diameter* means that the finer the thread the flatter the seam and the more the thread tends to bury itself in the fabric thereby minimising surface abrasion[114]. However, the sewing thread diameter is significantly higher after passing to-and-fro through the needle eye during sewing than what it is on the bobbin[14]. *Colour fastness* refers to the ability of the thread to retain its original shade during laundering and wearing[114].

Important chemical properties of a thread include resistance to chemical degradation, thermal and actinic degradation, insect damage and colour fastness to light, laundering, etc. Appearance and handle properties such as colour, lustre, softness and smoothness, etc. are also important[115]. The thread should also be resistant to detergents and bleaches[4]. In durable press processes where the garment is subjected to high temperature curing (up to 200° C), the sewing thread also has to meet stringent requirements as far as thermal stability (i.e. neither shrink, nor melt, nor lose its dye fastness) is concerned[68, 115].

Hot-stretching of synthetic sewing threads is often carried out to improve their dimensional stability, to reduce extensibility and to increase their length[115]. It is sometimes carried out after dyeing and entails heating the thread to a predetermined and controlled temperature, usually within the range 180° C to 240° C and at the same time controlling its length or tension[115]. The properties of some spun polyester after fluid bed processing (hot stretching) are given in Table VIII[115].

TABLE VIII

THREAD PROPERTIES

Staple polyester sewing threads — Fluid bed processing trials[115]

THREAD				THREAD PROPERTIES						
Nominal count	After final twisting			After hot-stretching (1 sec at 220° C)				After hot-stretching and dyeing on package (1 hour at 120° C)		
	Breaking load (N)	Exten-sion (%)	Shrinkage at 175° C (%)	Applied Stretch (%)	Breaking load (N)	Exten-sion (%)	Shrinkage at 175° C (%)	Breaking load (N)	Exten-sion (%)	Shrinkage at 175° C (%)
A 2/50 c.c. R23,6 tex/2 Kodel	9,2	14,2	7,90	0	9,0	14,6	1,85	9,3	17,5	0,46
				1,96	9,0	13,4	2,14	9,2	15,1	0,57
				5,0	9,1	10,8	3,53	8,9	13,5	0,83
B 3/100 Nm R30,0 tex/3 Trevira	14,1	13,9	8,91	0	13,5	12,7	2,93	12,9	14,9	0,72
				1,96	13,4	11,5	3,06	13,6	14,5	1,02
				5,0	14,0	9,5	4,46	13,5	12,9	1,66
C 3/63 c.c. R28,1 tex/3 Terylene	9,6	15,9	7,70	0	9,7	14,9	1,66	9,3	16,7	0,33
				1,96	9,8	13,6	2,01	9,7	16,0	0,44
				3,28	10,2	13,0	2,26	10,0	15,7	0,67
				5,0	9,7	11,0	2,93	9,7	14,5	0,72
D 3/84 Nm R36,1 tex/3	12,3	12,3	8,00	0	12,2	11,9	2,20	12,2	13,7	0,61

Loop strength of a sewing thread is more important than tensile strength[114, 117] and therefore the finest thread consistent with loop strength should normally be used. Table IX illustrates that tensile strength is not always correlated with seam strength[118].

TABLE IX

TENSILE STRENGTH AND SEAM PROPERTIES OF A NUMBER OF SEWING THREADS

Thread Type	Ticket Number	Average Sizing	Singles Metric Grist	Tensile Strength (grammes)	Average Seam Strength Results (Newtons)
Core-spun (soft finish)	80	80/3	25	1 450	216,8
Staple-spun Polyester	80	80/3	25	1 350	267,1
Staple-spun Polyester	100	101/3	34	1 150	187,0
Staple-spun Polyester	120	99/3	33	980	170,9
Core-spun (soft finish)	120	74/2	37	930	106,8
Cotton (mercerised)	60	101/3	34	760	90,8
Cotton (soft finish)	60	101/3	34	740	101,5

Two forms of abrasion resistance occur in the seam, thread-on-thread in the stitch and surface abrasion due to wear and cleaning[114]. If you could combine good durability with good sewability you would have the perfect thread but this is difficult and often a selection must be made as to which characteristics are the most important in a particular end use. Apparently no thread sews better than cotton or is more durable than synthetics[114].

Cotton will generally *outsew* synthetics mainly because of its low elongation, suppleness and heat resistance[119], whereas synthetics are more *durable* due to their higher elongation, tenacity and abrasion resistance. If, therefore, good *sewability* is of prime importance pick *cotton* whereas if durability is of overwhelming importance pick synthetics. Sewing synthetic fabrics with cotton threads can lead to seam failure because the cotton thread has a lower extension than the synthetic yarns. On the other hand sewing natural fibre fabrics with synthetic threads can sometimes lead to seam failure because of the thread cutting the fabric[4]. As a general rule cotton threads are used for cotton fabrics and synthetic threads for synthetic fabrics and for any easy-care fabrics which have little shrinkage[68]. However, sewing thread *per se* appears to have little effect on stitching damage although a finer thread may reduce loop damage when sewing knitted outerwear[14].

The seam is possibly the weakest link in a garment and it is also the lowest cost element in garment production — but cheap thread can represent a false economy[118]. Economics is, therefore, another vital consideration when it comes to the selection of a particular thread for a particular purpose[116]. It must be remembered that[119]: Cost of thread = Purchase Price + Cost of Sewing [sewability + cost of returns (durability)], Fitzmaurice[120] discusses the economics of various sewing threads, and he emphasizes that the sewability of a thread as well as its durability must be considered and not only price for arriving at its economics.

Actual sewing thread cost, as a percentage of the garments total cost structure, is generally small, and economy in sewing thread costs may be foolish since it could lead to a reduced labour efficiency, a far more important component of the total cost structure[121]. Current estimates put actual stitching time as merely 30% of the working day. Thread breakages and other stoppages render labour more expensive and reduce productivity. J & P Coats maintain that as long as the sewing thread strength exceeds a certain minimum further increases in strength are of little consequence. What is important is how the thread functions in the seam. On this score they claim their 100% all-polyester staple spun thread to be superior to the corespun cotton/polyester thread. It is estimated that a seam sewn with the staple spun polyester thread is 35% stronger than a corespun cotton/polyester seam even though size for size and grist for grist the spun polyester thread has a lower tensile strength. Hence it is possible to use finer, and therefore cheaper, spun polyester threads than the corespun ones in use, this being an added advantage for sheer and lightweight fabrics[121].

An instrument has been developed[122] which allows the thread consumption, both needle and looper thread, in a seam to be measured quickly and accurately. Previously the thread consumption was determined by unpicking the seam or by measuring the thread package before and after stitching[122].

Fig 9 and Table X compare the relative properties of different sewing threads[70]:

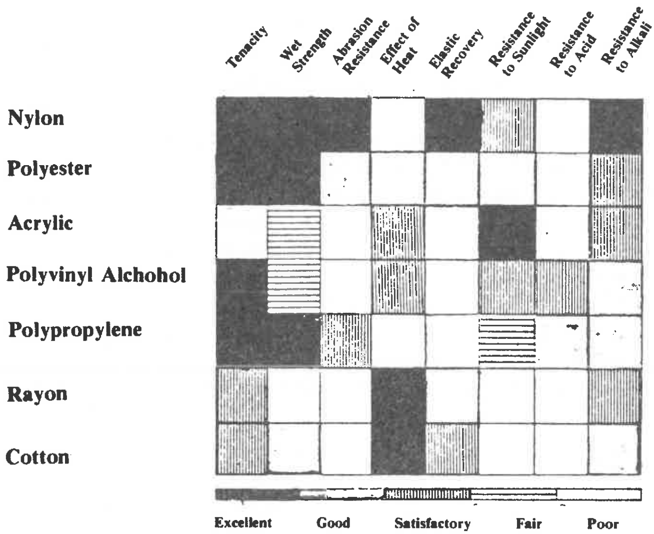


Fig 9 – The varying properties of different types of thread[70]

TABLE X

ABRASION RESISTANCE OF SEWING THREADS[70]

Abrasion resistance of sewing threads

The undernoted figures are based on J & P Coats standard thread-to-thread abrasion test and give an indication of the respective resistance to abrasion of various types of thread[70].

If Linen, Rayon C.F. has resistance of	=	1
Cotton	=	3
Spun silk	=	4
Pure silk	=	5
Vinylon	=	8
Polyester; staple spun	=	12,5
Polyester C.F.	=	30
Nylon; tow spun	=	40
Nylon C.F.	=	150

The abrasion resistance of a core spun thread is as good as that of its core.

Physical properties of some sewing threads used in one study[54] are given in Tables XI, XII. Tables XIII and XIV show the breaking load of some sewing threads[116].

TABLE XI

PHYSICAL PROPERTIES OF VARIOUS SEWING THREADS[54]

PROPERTY	MERCERISED COTTON					Cotton Terylene (core-spun)	C/F Terylene	C/F Pure Silk	Schappe-spun Polyester
	No. 1	No. 2	No. 3	No. 4	No. 5				
Linear Density (dtex)	552	440	360	309	200	267	311	284	296
Mean Breaking Load (N)	15,9	12,3	9,9	8,7	5,4	9,1	10,1	12,7	10,6
Tenacity (cN/Tex)	28,8	27,9	27,6	28,2	26,9	34,0	32,6	44,6	35,9
Minimum Breaking Load (N)	11,9	8,5	7,5	6,0	4,4	6,5	7,3	8,8	7,9
Minimum Knot Strength (N)	9,3	8,2	6,7	5,5	4,1	4,3	6,3	8,3	5,5
Minimum Sewn Knot Strength (N)	8,2	7,1	5,8	4,8	3,8	3,9	5,4	7,7	4,5
Mean Extension at Break (%)	8,7	9,0	8,6	7,1	7,5	15,3	18,0	18,2	16,0
Minimum Extension at Break (%)	6,5	7,8	7,4	6,4	6,5	12,0	13,4	14,4	13,2

TABLE XII

PROPERTIES OF R417 TEX/3 C/F TERYLENE THREAD[54]

Type of Test	Strength (N)		Extensibility (%)	
	Mean	Minimum	Mean	Minimum
Straight Tensile (Unsewn)	21,9	21,1	28,6	25,0
Straight Tensile (Sewn)	15,7	11,7	23,0	22,0
Knot Strength (Unsewn)	12,7	10,8	16,0	15,0
Knot Strength (Sewn)	11,7	9,8	19,0	17,5

TABLE XIII

COMPARATIVE BREAKING LOAD (N)[116] OF NYLON AND COTTON SEWING THREAD OF EQUAL DIAMETER

DESCRIPTION		BREAKING LOAD	
Nylon Size	Cotton Size	Nylon	Cotton
33 or B	60/4	20,0	8,9
46 or D	36/4	26,7	13,4
69 or E	24/4	40,1	17,8
99 or F	20/4	57,9	22,3
138 or 3 Cord	22/4	80,1	35,6
277	4 Cord	111,3	53,4
207 or 4 Cord	5 Cord	112,11	75,7
346 or 5 Cord	6 Cord	178,0	111,3
415 or 6 Cord	7 Cord	222,5	129,1
554 or 8 Cord	9 Cord	289,3	155,8
693	11 Cord	422,8	195,8

TABLE XIV

BREAKING LOAD (N)[116]

Sample Description		Silk	Mercerised Cotton	Nylon	Polyester
000	(100D)	6,7	8,0		
00	(140D)	9,4	9,4	11,1	8,9
0	(210D)	11,6	11,6	15,6	12,5
A		13,8	12,9		
B	(300D)	16,9	16,5	20,0	
C	(420D)	20,9	19,6	26,7	26,7
D		27,6	23,1		
E	(630D)			48,1	
	(840D)				53,0
No. 4 Cord	(2520)				155,4

Some UK thread suppliers are listed in Table XV[68].

6.2 Types of threads and their properties

6.2.1 Cotton threads

Only the best qualities of cotton are generally used in sewing threads[123]. Cotton threads are generally produced along the combing route, with S twist in the singles and Z twist in the ply form, balanced twists being used to avoid snarling. Dyeing and finishing produce what is termed "soft" cotton threads which are generally cheapest while the highest quality cotton threads are mercerised (more expensive) to improve lustre and strength, this being carried out after plying but prior to dyeing[124]. These threads are also generally singed by gas flames or electric burners. Some threads, e.g. those used on leather, need a very smooth finish which is obtained by a polishing process after dyeing. This involves the impregnation of the threads with a mixture containing starches and waxes after which they are brushed to dry and lay the fibres and develop a polish. These threads are described as "polished" or "glace" threads. Rayon has not replaced cotton to any great extent because of its lower strength and abrasion resistance[124].

Staple length has a decisive influence on subsequent sewing thread quality, the longer the staple the stronger the thread and the finer the thread which can be spun[118]. *Yarn evenness* also has a bearing on sewing thread quality, this often being assessed by blackboard winding. Permissible yarn imperfections are basically

TABLE XV

UK THREAD SUPPLIERS — BRAND NAMES[68]

Manufacturer	Seam-Stitching Threads			Auxilliary Threads (mainly overlocking and bobbin thread)		Special Purpose Threads		
	Polyester/ cotton core-spun	100% Polyester spun staple	100% cotton spun staple	100% polyester multi-filament	100% nylon multi-filament	Bulked continuous filament nylon or polyester	Nylon Mono-filament	Others
Barbour	Terko	Respol (Schappe-spun)	Hilbran	Weaverbird 200	Lynyl	No. 80 (Nylon)	Mono-filament	Linen Threads
J & P Coats	Koban	1. Drima-T (cotton-spun) 2. Drima (Schappe-spun)	1. Golden Bagley 2. Super Sheen (Merce-rised)	Gral 200	Aptan	Aptan (Nylon) 80 & 100	Sonal	Drima (staple-spun nylon for stretch)
Donisthorpe	Don Blend	Donistex (Cotton-spun)	1. Ivy (Merce-rised 2. Ibex (Soft)	Don Maid M.200		Ibex 80 (Nylon)	Coloripic	Doncel (Vincel)
English Sewing	Polyfil	Terral (cotton-spun)	1. Sylko (Merce-rised 2. Neilson Super 3. Oriental	Zenith	Dewlon	Delta (Polyester)	Monovic	1. Trylco for seam stitching (texturised multi-filament polyester) 2. Terral 30 for decorative stitch 3. Syntoc (staple spun polyester for stretch)
Peri-Lusta		Peri-Lusta (Schappe-spun)	Peri-Lusta Merce-rised				Peri-Lusta Super Soft	Sericum (staple spun cotton for overlocking)
Perivale-Guterman		Mara (Schappe-spun)		Skala U.151 (bonded filament) Tera (twisted filament)		Bulon (Nylon)	Diva	Mara M.100: and M.2654 (spun polyester decorative thread)

"faults" which can pass through the needle eye without interrupting the sewing process. Damage to the cotton fibre is often assessed in terms of fluidity[118].

It has been stated[125] that cotton thread is excellent in sewing capability and speed, durability, strength, colour fastness, etc. but has the following draw-backs: 1) Cotton price is unstable, and 2) synthetic fabrics are becoming more popular and these are generally best served by synthetic threads.

Cotton threads are generally good but strength and abrasion resistance are inferior to equivalent synthetics[126] but they are, however, less affected by needle heating and high temperature pressing[126]. Cotton threads stretch by 6% at most before breaking whereas synthetic threads can extend by as much as 30% without failure. Abrasion in the tumble dryer weakens cotton threads more than synthetic threads, the latter having twice the abrasion resistance of the former[65]. Chlorine bleach, if misused, can attack cotton and destroy it whereas synthetic threads are more resistant to it. Because of their greater tenacities, finer synthetic threads can be used than is the case for cotton and this can improve seam life since the finer thread buries itself in the fabric and is not so exposed to abrasion.[65]

Cotton is claimed to be impervious to perspiration and largely resistant to the effect of lyes (caustic soda). It is also dyed with good dye fastness to light, washing, boiling, weathering, ironing, perspiration and chlorine[123].

Cotton thread is the easiest to use on the sewing machine[65] although it can lead to puckering after washing or dry cleaning, since, although it has low shrinkage on the holder, it can become stretched during sewing which then leads to shrinkage during laundering and consequently puckering. Generally, with synthetics, a puckered seam manifests itself shortly after completion of the garment since the synthetic threads, if stretched, quickly return to their original length[65]. Machine sewing with cotton threads causes fluffing and also increases the apparent thickness of the thread due to a loosening of the thread construction[127].

6.2.2 Synthetic threads

Synthetic sewing threads may be divided into the following groups according to their construction[119]:

Multifilament — the first successful synthetic thread developed.

Monofilament — a single solid filament like fishing line and is usually clear.

Core thread (Corespun) — consists of a multifilament core around which is wrapped a cotton cover or sheath.

Spun — this involves the processing, on the cotton system, of pre-cut synthetic staple.

Textured — thread produced from multi-filaments which have been textured.

The production of synthetic sewing threads has been discussed in one article[128]. The most popular synthetic thread compositions are[119]:

1. Textured, monofilament and multifilament threads are available in nylon and polyester with small amounts of multifilament rayon available.
2. *Core* (corespun) threads are generally available in polyester/cotton and to a much lesser extent in nylon/cotton.
3. *Spun* threads are available in polyester and rayon.

Some details of "Terylene" sewing threads are given in Table XVI[129]. Some details of polyester filament and corespun threads are given in another publication[130] as well.

The outstanding strength of synthetics has proved a particular boon for heavy duty sewing such as luggage. At the other extreme, light lingerie fabrics are now being produced from fine, delicate seams using fine threads strong enough to withstand the constant abrasion, flexing and laundering stresses and still outlive the garment[68]. No natural fibres can match the synthetics as far as their resistance to mould, decay and perspiration are concerned[112].

To minimise puckering the sewing thread has to be shrink-resistant during washing and ironing, synthetics being preferable[61]. Synthetic threads generally exhibit lower shrinkages in dry-cleaning and normal working conditions, an essential requirement if puckering is to be avoided in minimum-care garments[61].

The most important synthetic thread used for sewing thread is polyester, particularly in the clothing industry[124]. Polyamide is suitable for other uses including the sewing of leather[124]. Polyester core-spun, spun or filament threads are generally recommended for knitted fabrics since these have better extensibility than soft or mercerised cotton threads. Furthermore, their greater strength allows finer threads and needles to be used[32].

Synthetic rather than cotton threads are recommended for knitted fabrics[131], with polyester preferred to nylon due to its higher

TABLE XVI

STRENGTH AND RUNNAGE OF TYPICAL 'TERYLENE' SEWING THREADS[130]

TYPE OF THREAD	Resultant count (approx.)				Breaking load		Runnage (approx.)	
	den	decitex	c.c.	Nm	lb	N.	yd/lb	m/kg
100% 'Terylene' Filament								
2/63 den	140	155	38	64	2,0	8,8	31 600	63 800
3/63 den	210	235	25	42,5	2,8	12,7	21 100	42 500
3/125 den	420	465	13	21,5	6,0	26,5	10 600	21 400
3/250 den	840	935	6,5	10,5	11,9	52,9	5 300	10 700
3/750 den	2520	2800	2	3,5	35,6	157,8	1 770	3 570
'Taslan'-textured 'Terylene' Filament								
3/75 den (nominal)	265	295	20	34	1,8	7,8	16 850	34 000
'Terylene'/Cotton Core-spun								
2-ply (63 den 'Terylene' + 40% cotton)	235	260	23	38	2,0	8,8	19 000	38 300
2-ply (125 den 'Terylene' + 30% cotton)	400	445	13	22	4,0	17,6	11 150	22 500
3-ply (125 den 'Terylene' + 30% cotton)	600	665	9	15	6,0	26,5	7 450	15 000
3-ply (250 den 'Terylene' + 20% cotton)	1050	1170	5	8.5	12,0	52,9	4 250	8 570
3-ply (750 den 'Terylene' + 20% cotton)	3150	3500	1,7	2,9	36,0	159,7	1 420	2 860
100% 'Terylene' Staple								
2-ply	195	215	2/55	93/2	1,2	4,9	23 100	46 500
3-ply	205	225	3/78	132/3	1,5	6,9	21 800	44 000
3-ply	285	315	3/56	95/3	2,3	9,8	15 700	31 700
100% Cotton								
Ticket No. 90's	205	225	3/78	132/3	1,1	4,8	21 800	44 000
Ticket No. 40's	445	490	3/36	61/3	3,2	14,7	10 100	20 300

initial modulus. Polyester, therefore, sews better than nylon and gives as good strength in the seam. Its chemical resistance is superior to nylon, particularly resistance to chlorine bleach. Polyester can also be stabilised giving low shrinkage and reducing the risk of puckering. Cotton/polyester corespun thread is regarded as the best all-round thread. A thread stretched too much during sewing can lead to skipped stitches, a weakened seam and also to pucker[131].

For knitwear, Perivale-Gütermann advise the use of their Schappe-spun polyester thread, Mara, or multi-filament, Tera, for the needle thread, with bulked nylon thread, Bulon, in the loopers. Similar threads are supplied by other thread manufacturers.

Nylon threads are suitable whenever fine stitching must combine with heavy duty performance. Polyester is recommended where a high degree of fastness to light, weather and acid is required. They also possess great elasticity and are easy to sew[112]. Nylon is degraded by light in general whereas polyester is mainly sensitive to ultra-violet light[70], and the latter is generally preferable when the seam is exposed to light, particularly behind glass.

The major advantages of the various threads are as follows[119]:

Rayon — very low cost

Nylon — high elongation and best abrasion resistance

Polyester — resists most acids.

A stabilized *core* thread has approximately 17% elongation, cotton has approximately 7%, stabilized spun polyester approximately 15% and filament nylon as high as 27%. Although elongation is important, elasticity (i.e. elastic recovery) is even more important[119]. Although synthetic filament threads offered many advantages, they also presented many problems during sewing[116].

Nylon fibre is not resistant to chlorine bleach[70] but is more resistant to alkalis whereas polyester threads are more resistant to acids making them largely unaffected to many types of perspiration. Their other properties are similar. Both are rotproof and resistant to bacteria, an important consideration in tropical wear. Their high abrasion resistance, that of nylon in particular, is probably their second most important advantage after strength. They are also resistant to dry cleaning solvents and are shrink-resistant, apart from having favourable stretch and recovery properties. They are suitable for permanent or durable press garments provided the dye is fast to heat, i.e. will not sublimate in the curing oven or through hot head pressing. Thread abrasion resistance is very important[70].

Nylon sewing threads have outstanding properties such as high strength, abrasion resistance and impact strength and typical end-uses include shoe industry, auto upholstery, apparel, wash and wear apparel, tents, awnings, etc.[116] Nomex has high heat resistance and is, therefore, suitable for flame retardant clothing. Teflon fibre has high heat and chemical resistance and can, therefore, be used to advantage in chemical application and filters. Nylon thread is used extensively by shoe manufacturers to stitch the uppers[116].

6.2.2.1 Textured Threads

Textured threads are generally air-textured (Taslan process) and they present less problems of thread fusion and also "lock" better in the seam[77] than continuous filament threads.

They give flatter seams and better seam elongation at a lower price than any other synthetic thread. They do not, however, sew on all machines, are difficult to rip out when repairing a seam and have low abrasion resistance. They are also affected by needle heat[119]. Textured yarns are used because of their special characteristics such as softness and their ability to provide cover and locking in the seam[124].

Bulked (crimped) polyester or polyamide threads are produced with a low twist so that their bulking characteristics are not destroyed. *Bulked* filament threads obtained by plying together yarns which had previously been bulked (by the false twist process usually), are suitable as *looper* threads[77].

Textured polyester thread can be used as an underthread on just about any machine[131]. It can be used as a needle thread only on chainstitch machines. While it is more heat resistant than multifilament threads it is not as good as spun or core when needle heat is a problem. In the seam, the textured thread has the poorest abrasion resistance of all the polyester threads mainly due to the more exposed nature of the filaments. Textured threads are, however, excellent for non-stress uses such as serging or cover thread since they are cheap[131].

Recently, a new transluscent multifilament textured polyester sewing thread has been introduced[132]. It has a shrinkage of 1,5% in boiling water, is half the price of core-spun threads and one-third the price of spun polyester threads. A new finish is claimed to reduce the problems of needle heat and it showed good abrasion resistance[132].

6.2.2.2 Monofilament threads

Monofilaments are translucent and are usually available as "white" (clear) or grey brown ("smoked" colour), the former being used for white or pastel shade garments and the latter for darker or solid shade fabric[77, 133]. They are generally more expensive than textured threads but cheaper than other synthetic threads. However, easy matching is possible eliminating continuous changing of thread colours and it is not necessary to stock up with a wide range of colours[133].

Several thread manufacturers maintain that monofilament threads are harsh and that wearer trials have shown that the edges of overlocked hems and seams can irritate the skin[68, 77, 119]. Others maintain, however, that because of their cheapness they are being used in areas for which they were not originally intended[68]. Fine monofilament threads sink completely into jersey and surface texture fabrics and overlocked edges containing such threads have no effect on the sheerest tights and cannot be felt on the skin.

Continuous mono- or multi-filament (twisted in the case of the latter) synthetic yarns have two possible disadvantages. They are prone to needle heat damage at high sewing speeds and their smooth surface can cause spillage and run-back when threads are cut through in the process of trimming seam ends[77]. Bulking or texturing, however, helps to overcome these problems since the minutely looped surface of the thread reduces contact with the needle and the entrapped air cools the needle.

Monofilaments can be comparable in cost to cotton while silk threads are relatively expensive. The use of polyester filament in industrial sewing threads has been considered in one article[134] and the application of monofilaments in another[133].

6.2.2.3 Multi-filament threads

Continuous filaments (either polyester or polyamide) are twisted to bind the individual filaments together and to protect them against abrasion and sewing[124]. Usually a number of such yarns are twisted together to form a plied thread[124], stretched if necessary to reduce elongation, the twist balance set and finally finished with a lubricant[116]. The raw filament yarn is either used as it is or rewound onto bobbins for uptwisting. For needle threads, high twist levels are employed to produce a circular cross-section which will not flatten or distort thereby reducing damage as a result of needle heat and abrasion[116].

High singles twist may necessitate steam setting prior to plying so as to obviate snarling. Needle threads generally used for apparel require ply twist between 80 and 90% of the singles twist[116]. Balanced yarns are essential and most sewing machines require threads with Z twist and a corresponding S twist in the singles yarn.

Stretching, bonding, or both, may sometimes be carried out prior to the lubricant being applied. Stretching is generally carried out at an elevated temperature, care being taken to ensure the thread is dimensionally stable to laundering and making up. A maximum of 3% residual shrinkage at about 150°C has been suggested as an upper limit[116].

Multifilament threads are available with bonded finish (Bonded Twisted Thread)[116] which bind the filaments together giving a high abrasion resistance which is highly durable for heavy sewing operations[124]. This is a conventional thread that has been covered with a protective plastic coating[124] and is generally meant to meet the most severe demands of performance. They are sometimes welded rather than bonded and can be either stretched or not stretched[116]. The bonding involves the uniform application of a given quantity of bonding agent (PVC or Urethane type of resin) to the thread after which a lubricating finish is applied. *Low-twist filament* threads are *bonded* with nylon bonding more readily than polyester[77]. Bonding reduces damage due to needle heating and also prevents cut ends from fraying or broken filaments from flying out. These threads are mainly used in high speed heavy duty sewing, for example stitching a leather facing or front to a knitted garment[77].

Multifilament polyester threads are more difficult to sew with than spun threads and are very heat sensitive, frequently requiring lower sewing speeds[131]. They are also abrasive on machine parts, as is the case with spun polyester threads[131].

Continuous multifilament sewing threads contribute to needle heat whereas spun or core-spun sewing threads have surface hairs which transport cooling air to the sewing needle[26]. Furthermore, part of the heat generated is carried off by the air stream generated by the spun thread. Using spun threads can allow an increase in sewing speed of up to 10%. The needle heat can either damage or fuse a synthetic sewing thread[26]. With multiple filament synthetics broken filaments can cause a blockage at the needle eye. The bits of molten residue can stick to the needle causing problems and the changes in the thread elasticity due to temperature changes can be reflected in the seam[26].

Continuous filament threads have a tenacity of some 70% higher than that of cotton threads[77]. Used as spool thread, the former gives less downtime as a result of fewer spool rewindings (i.e. longer lengths can be accommodated on the spool). As a needle thread, however, it can be subject to fusion[77]. Multifilament threads offer the best seam abrasion resistance, have good tenacity and elongation but are relatively expensive[71]. Sometimes problems with stitch slippage, run-back and needle heat can occur[71].

6.2.2.4 Staple threads

Spun synthetics are weaker than filament threads often necessitating the use of coarser threads[119] although often a spun synthetic thread with a high strength to fineness ratio allows a fine needle to be used and gives a good all round performance[12]. Their fuzzy nature minimizes thread slippage in the seam and runback, and sew better than filament synthetics. They have lower elongation characteristics than filament threads and are cheaper than multifilament and core threads but more expensive than monofilament and textured threads[119]. They are also affected by heat[119], but the hairy surface of the yarn reduces needle heating since it carries cool air to the needle[12].

Singeing of 100% synthetic staple sewing threads may not always be essential. Surface fibres protruding from the staple threads appear to serve a useful function in absorbing heat at the needle eye and thereby protecting the body of the thread, provided the needle temperatures are not excessively high. Singeing, if required, should be carried out after dyeing and prior to lubrication[116].

The polyester thread is strong, has good heat resistance and is a good all-purpose thread[68]. English Sewing added a spun staple polyester (Star) to their existing synthetic threads, viz. continuous filament textured (Trylko) and corespun (Polyfil)[135]. Details of the thread are given in Table XVII below[135]. It has a moisture regain of 0,4% compared to that of 4% for "Polyfil".[135]

TABLE XVII

Ticket No.	Ply	Approx. dtex	M/kg	Typical Strength (N)
30	3	1 060	9 400	3,6
80	3	400	25 000	1,2
120	3	320	31 250	9,4
180	2	210	47 600	6,1

For heavy duty seaming corespun (Polyfil) is recommended whereas spun polyester (Star) is preferred for low flammability[135].

Spun polyester is a good all-round thread but is more difficult to sew with than the cotton sheath/polyester core thread. It tends to increase needle heat, is more prone to damage by needle heat and it is more abrasive than the corespun product[131].

There are claims that spun polyester thread is cheaper than corespun thread[131,136], reduces lint build-up due to peel-back of the cotton wrap and increases seam strength[136]. Price stability of polyester *vis-a-vis* cotton is regarded as another plus for spun polyester sewing threads[136]. Spun polyester is claimed[136] to provide a 15% — 20% savings over corespun threads of comparable single thread strength.

6.2.2.5 Core-spun threads

The core-spun thread generally consists of a polyester filament core and a cotton sheath (outer surface)[137]. The production process for core-spun sewing threads include spinning, steam setting, dyeing, singeing, heat treatment and lubrication. Filament yarns ranging from 55 to 944 dtex (50 to 850 denier) are used as core, with complete coverage of the core not always essential[116]. With coarse cores the staple fibre content (sheath) may be as low as 15 to 20%. Another article states[77] that the average core-spun thread has $\simeq$ 25% cotton. The cotton gives the thread excellent sewability whereas the synthetic core imparts higher strength[137] compared to the equivalent all-cotton thread. This makes it possible to use a finer thread and yet retain the same seam strength. The synthetic core can also limit the washing shrinkage of the thread to approximately 1%[68]. Core-spun polyester threads are less susceptable to needle heat damage since the cotton sheath insulates the polyester core[68]. The cotton covering (sheath) also gives the thread its soft surface[137].

Initially core-spun thread was developed to improve the sewing performance of the synthetic sewing threads available at the time[137], a thread being required which combined strength with good resistance to heat. Core-spun thread is claimed to resist moisture, rot, acid and bacteria and is unaffected by perspiration. It has good resistance to shrinkage (the soft finish being even better than the glace in this respect), yet it is sufficiently supple and elastic in the seam to contract or expand with the material, a feature which makes it suitable for seaming stretch fabrics. The cotton covering also provides security against run-back at the start or finish of a seam and because of its friction resisting properties is particularly useful on high-speed machinery. The twist balance of these threads counter snarling and make them more amenable than many continuous filament threads to threading, knotting and manipulation. Compared to all-cotton threads, a core-spun thread being stronger, can be correspondingly finer allowing a finer needle to be used which is less likely to damage the material and cause seam pucker in a closely woven fabric. Furthermore, a seam sewn with the finer thread has an extremely attractive appearance. In addition, fewer bobbin changes are necessary with a finer thread because of the longer length of thread which can be accommodated[137].

Core-spun thread is regarded as the optimum for sewing knits, and the finest thread consistent with seam strength requirements should be used[138]. Core-spun threads are regarded as particularly suitable for sewing jeans and recommendations have been made concerning the choice of thread and needle[139]. Maximum advantage is often derived from core-spun sewing threads when it is used in conjunction with a filament yarn thread (e.g. Terylene) in the under-bobbin[116, 129], the filament thread giving long lengths of thread on the spool and therefore long runs.

The J & P Coats core-spun threads (Koban) are produced in nine sizes ranging from ticket 180 to ticket 8[137]. The finest sizes (Koban 180 to 120) come in the soft finish, the medium sizes (Koban 75, 50 and 36) are available in either soft or glace finish, while the coarser sizes (Koban 25, 18, 12 and 8) are available in glace only. The cones or vicones on which the thread is wound are colour-coded according to the thread size. Some 300 thread shades are available and offered for the Koban 120 size and more than 125 for Koban 75[137].

Core-spun threads are regarded as the most versatile of all sewing threads[137] and they suit virtually all types of fabric. In the finest sizes (180 to 120 tickets) they are ideal for underwear, shirts, blouses, dresses and other lightweight fabrics. Ticket 75, which is the size most in demand, is an all-purpose tailoring thread, suitable for seat-seaming, hand-felling and practically all general seaming. It is also useful for corsetry, swimwear, overalls and rainproof and windproof outerwear. The middle sizes, tickets 50, 36 and 25, are used for heavy clothing and heavier outerwear such as jeans. For the bold seams that are often required in jeans, ticket 36 is suitable. Glace core-spun is probably the most successful handsewing thread yet introduced for general tailoring applications including button stitching. The coarser core-spuns, tickets 18, 12 and 8 are widely used for stitching haversacks, webbing equipment and other heavy-duty products. Core-spun threads can also be used for stitching leather, e.g. footwear, sheepskins, protective clothing, gloves, belts, etc.[137] Polyester core threads are claimed[117] to be the optimum for knitted fabrics.

In the seam, the cotton covering tends to expand, filling the needle hole and helping to resist water penetration of the seam[137]. These threads are, therefore, also used for stitching tents, tarpaulins, awnings, protective clothing and even divers' wet suits. A waterproofed finish has also been developed[137].

Tables XVIII — XXV show some properties of core-spun threads which have been published[134].

6.2.2.6 Auxiliary threads

Auxiliary threads are mainly used for overlocking and blind stitching and as a shuttle or bobbin in lockstitch seams and consist of multifilament polyester or nylon threads with the filaments twisted and heat-set or sometimes bonded together to prevent separation during stitching[68]. They are, however, not textured as in the case for the previously mentioned seam stitching threads.

Auxiliary threads are generally cheaper and finer and come in larger packages than the seam stitching threads, Sometimes they are used as needle threads in lockstitch and chainstitch seams in lightweight garments.

6.2.2.7 Special purpose threads

Textured continuous filament nylon or polyester threads are used for overlocking or seam covering. These threads are soft and bulky and form a very good covering for seam edges, including looper threads for safety stitches. When used as a needle thread for chainstitch, a special threader has to be used to guide the thread through the needle because of its textured character[68].

TABLE XVIII

PROPERTIES OF SOME CORE-SPUN THREADS[134]

PARAMETER	No. of filaments: 24			36			48			72		
	Single	Two-Ply		Single	Two-Ply		Single	Two-Ply		Single	Two-Ply	
		Undyed	Dyed		Undyed	Dyed		Undyed	Dyed		Undyed	Dyed
Linear Density (dtex)	209	222,0x2	236,2x2	208	220,3x2	236,4x2	210	219,4x2	233,3x2	214	220,3x2	234,1x2
Cotton Covering (%)	29			26			28			28		
Breaking Strength (N)	9,03	18,3	17,6	9,67	18,7	17,9	9,35	18,0	17,1	9,99	19,4	18,1
Extension at Break (%)	19,5	23,2	29,5	21,5	21,7	28,3	22,3	21,7	30,4	21,4	21,5	28,8
Coefficient of Cohesion	100			89			113			167		
Loop Strength (N)		25,1	23,9		26,4	20,2		24,6	23,3		25,6	22,5

TABLE XIX

PROPERTIES OF CORE-SPUN THREADS (NON-STABILISED)[134]

PARAMETER	NUMBER OF FILAMENTS			
	24	36	48	72
Linear Density (dtex)	234x2	241x2	240x2	240x2
Breaking Strength (N)	17,7	18,5	17,7	18,3
Extension at Break (%)	31,9	30,9	31,0	29,1
Loop Strength (N)	26,0	26,1	25,3	26,1
Z Twist (turns/m)	906	878	902	890
Cotton Covering (%)	28	27	27	25
Resistance to Sewing (daN)	31,9	30,9	32,7	33,2
Rigidity Coefficient	100	93	79	70
Resistance to Flex Abrasion (cycles)	311	364	346	452
Washing Shrinkage (%)	0,6	0,7	0,6	0,7
Heat Shrinkage (%)	2,7	2,9	1,4	1,4

TABLE XX

THREAD BREAKING STRENGTH AT DIFFERENT STAGES[134]

STAGE OF MANUFACTURE	BREAKING STRENGTH
Single Flat x 2	18,6
Single Core-spun x 2	19,0
Plied	18,6
Dyed	17,7
Finished	18,0

TABLE XXI

LOSS OF STRENGTH AFTER SEWING[134]

Number of Filaments	24	36	48	72
	8%	17%	20%	22%

TABLE XXII

LOSS OF STRENGTH AFTER SEWING[134]

PARAMETER	NUMBER OF FILAMENTS			
	24	36	48	72
Breaking Strength before Sewing (N)	8,57	8,59	8,61	9,34
Loss of Strength after Sewing (%)	27	27	39	53

Some special purpose threads include nylon staple fibre threads with added elasticity for linking knitwear and which is also used in foundation wear and swim wear. There is also a special spun staple cotton for overlocking whilst linen thread is preferred for certain end uses such as button-sewing for tailored garments.[68]

A well known special purpose thread is the monofilament nylon translucent or invisible thread which must not be confused with the term "semi-translucent" often applied to the multi-filament polyester auxiliary threads some of which reflect the colour of the fabric thereby reducing the number of different thread colours required[68]. The monofilament threads are sufficiently transparent to blend with many different shades of fabric and are extruded to the required linear density (55 to 833 dtex or 50 to 750 denier) although the main sizes for clothing are 89, 200 and 278 dtex (80, 180 and 250 denier). Its use for overlocking and blind-stitching has led to considerable savings in cost and stock-keeping but because the coarser threads are rather

TABLE XXIII

PROPERTIES OF BONDED FILAMENTS[134]

PARAMETER	NON-STABILISED YARNS				STABILISED YARNS				
	Number of Filaments				Number of Filaments				
	24	36	48	72	16	24	36	48	72
Linear Density (dtex)	172		178	168	153,9	157,6	155,1	160,2	169,8
Breaking Strength (N)	8,66	8,33	8,56	9,16	8,69	8,03	8,28	8,10	7,85
Extension at Break (%)	32,5	31,9	32,7	30,2	22,2	22,6	22,2	24,2	26,4
Loop Strength (N)	11,6	12,6	13,3	13,7	8,74	9,80	10,65	12,03	13,11
Resistance to Sewing (daN)	12,8	14,0	14,3	16,1	9,8	11,7	12,8	14,0	15,4
Resistance to Flex Abrasion (cycles)	53	82	77	118	56	70	93	140	127
Rigidity Coefficient	100	104	62	85	100	84,3	63,3	71,1	69,9
Heat Shrinkage (%)	2,1	1,8	2,0	1,9					

TABLE XXIV

PROPERTIES OF FLAT YARNS AND STABILISED FILAMENTS[134]

PARAMETER	NUMBER OF FILAMENTS				
	16	24	36	48	72
Linear Density (dtex)	136,7	136,6	137,0	144,3	150,8
Breaking Strength (N)	8,77	8,69	8,98	8,60	8,43
Extension at Break (%)	17,5	16,1	16,5	19,3	21,9
Tenacity (cN/Tex)	64,2	66,3	65,5	59,6	55,9
Modulus at 2% (cN/Tex)	618,0	660,0	628,0	580,0	537,0
Loop Strength (N)	8,9	10,5	11,6	13,0	14,0
Shrinkage at the Boil (%)	1,5	1,8	1,5	1,2	1,1
Shrinkage at 150°C (%)	3,4	4,1	3,7	2,9	2,2
Shrinkage at 180°C (%)	6,8	7,6	6,8	6,0	5,3

TABLE XXV

PROPERTIES OF CORE-SPUN YARNS (STABILISED)[134]

PARAMETER	NUMBER OF FILAMENTS				
	16	24	36	48	72
Linear Density (dtex)	223x2	214x2	226x2	222x2	234x2
Breaking Strength (N)	15,6	16,8	16,9	15,9	16,1
Extension at Break (%)	20,1	22,0	20,9	22,0	27,3
Rigidity Coefficient	100	76,3	60,2	51,7	43,2
Resistance to Flex Abrasion (cycles)	115	150	209	252	305
Heat Shrinkage (%)	2,9	2,5	2,6	1,9	1,9
Maximum Sewing Tension (N)	17,4	14,3	14,0	10,1	12,8
Resistance to Sewing (daN)	24,2	25,6	23,7	27,6	28,3

stiff, care must be taken to use as fine a thread as possible for areas where the thread could come into contact with the skin[68].

For post-cure systems, such as Koratron, the thread must be chosen to withstand the heat of the oven — generally about 165°C for 20 minutes after the hot-head pressing, where 180°C is the temperature recommended for Terylene blend fabrics and 200°C for Dacron blends, applied only for 15 to 20 seconds. This is barely time for the heat to penetrate either cloth or thread. Pre-cure systems on the other hand, require temperatures as high as 220°C although for very short periods[58]. Hot-head pressing is, however, often not as dangerous as the domestic iron in the hands of a careless consumer.

At ironing tempertures above about 200°C, combined with uncontrolled time and some pressure, a great danger is a change in the shade of the parts being ironed. Dyestuffs are not normally fast at such temperatures and the sewing thread can also suffer[58]. Sublimation fastness testing of dyes on sewing threads destined for permanent press garments is generally carried out by sandwiching the thread between white cotton calico and polyester cloths and then heating them to 175°C for 10 minutes.[70]

Spun staple polyester was originally developed for permanent press, stabilised to withstand high temperatures without shrinkage or shade change. Core-spun polyester/cotton threads, also heat-set during manufacture, proved equally suitable for permanent press systems. Threads for overlocking are less critical because any heat-shrinkage has a less serious effect as looper threads than for steam stitching. This means that, if oven treatment is involved, nylon 6 and 6.6 are passable for overlock loopers but not for seams[58]. Nylon's oven-shrinkage is still a problem, which applies to pocketings and waistbandings in addition to threads. Koratron, therefore, generally recommend polyester[58].

A thread which will withstand almost any temperature is Du Pont's Nomex. It has a high melting point and can easily be taken to 400°C[58]. Two such threads are produced by Perivale-Gütermann in spun form (Saltaspun) and continuous filament (Salta) for operations where high needle heat is unavoidable (e.g. footwear) or where the garments may be exposed to very high temperatures. Fire fighting suits (e.g. tank suits for the army and racing driver suits) are the main end-uses for such threads which are relatively expensive[58].

For flame resistant garments a sewing thread should be chosen which is compatible with the material used[138]. It is also advisable to keep thread fineness (diameter), thread length, stitches per cm and seam allowance as low as possible. It is not advisable to add your own finish to the sewing thread, when flame resistance is required. For instance, silicone (a common ingredient in thread finishes) can increase the likelihood of excessive burning. The same applies to the use of silicone sprays in the seam area. Spun polyester threads are generally best for flame resistant fabrics[138]. Factors affecting seam flammability have been discussed by Jakes *et al* [140].

6.3 Yarn Twist

Except for monofilaments, all threads are twisted. Insufficient twist can lead to fraying and breakage at the needle hole while excessive twist can cause sewing difficulties due to snarling, looping and knotting. Plying twist is generally in the opposite direction to the singles twist so that a balanced thread is produced which will not unravel[68]. The choice of twist usually depends on the direction of rotation of the sewing machine hook or the location of the looper[114]. Most threads are supplied with Z-twist (left) since it is suitable for most sewing machines[70]. Corded threads (up to 12 and 16) are formed by twisting together plied yarns, once again the twist being in the opposite direction to the previous twist direction used. The final S and Z twists are often called *right* and *left* hand twists, respectively, although S twist is really only needed by flatlock and one or two other specialised machines, e.g. buttonhole machines[68,141].

All two-and three-ply sewing threads are twisted once and are known as "single-twist" or "direct-twist" threads. The thread is always wound in the opposite direction to the turn of the twist[112]. Twisting together two or more single yarns with the aid of a pretwisting process produces a "rough twist". A subsequent further process unites two or three "rough twists" by means of a so-called "after-twist" in the opposite direction to produce an "outward twist". Well-known "double twists" such as the four-ply "Obergarn" are produced in this way. (See Fig 10). After twisting comes the very important finishing process.

Mercerisation, for instance, is applied to three-ply "direct twists" to give them a silky lustre. It also improves strength and the absorption of dye.[112]

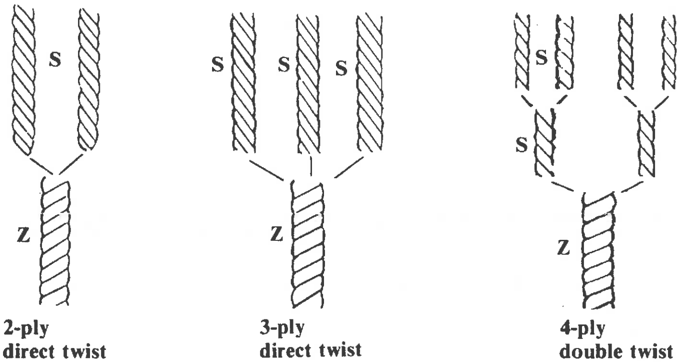


Fig 10 – 2-ply direct twist, 3-ply direct twist and 4-ply double twist.

The singles tex twist factors generally lie between 22 and 36 (2,3 to 3,7 English cotton twist factor). Higher twist factors generally produce more extensible yarn. Steaming may be essential for twist lively yarns. For needle threads, the plying twist is generally about 90% that of the singles yarn[116].

6.4 Sewing Thread Lubrication

The introduction of synthetic sewing threads together with higher sewing speeds have required different and better thread lubricants[21]. The requirements of an ideal sewing thread lubricant are given in Table XXVI while the effects of fluid viscosity of the lubricant on needle temperature and sewability are given in Tables XXVII and XXVIII[21].

TABLE XXVI

PROPERTIES OF THREAD LUBRICANTS

Ideal	Silicone	Organics
Colourless	Colourless	Satisfactory
Safe to use	Safe to use	Safe to use
Inexpensive	Highly cost efficient	Cheap, but often technically acceptable
Low friction	Low friction	Not as effective as silicones. Very poor at high temperature
Even friction	Organosilicones are good	Waxes are good
Inert to dyes and fabrics	Inert	May cause dye transference in contrast stitching during high temperature setting
Prevent decomposition of thermoplastic polymers by hot needles	Minimise heat build up. Inhibit heat transfer	Inefficient needle coolants unless very high percentages are used

TABLE XXVII

VARIATION OF NEEDLE TEMPERATURE WITH FLUID VISCOSITY. THREAD – STAPLE SPUN POLYESTER. MEASURED USING THERMOCOUPLE TECHNIQUE

Fluid	Pick-up	Needle temperature
Untreated	—	230°C +
Solid organic	4%	193°C
DC 200/50	4%	192°C
DC 200/1 000	4%	190°C
DC 200/12 500	4%	169°C
DC 200/60 000	4%	162°C

TABLE XXVIII

EFFECT OF FLUID VISCOSITY ON THE SEWABILITY OF POLYESTER SEWING THREAD

Fluid	Pick-up	Relative number of breaks
None	—	5,6
Solid organic	4%	2,8
DC 200/50	4%	2,9
DC 200/350	4%	2,8
DC 200/1 000	4%	2,4
DC 200/12 500	4%	1,0

All sewing threads require a lubricant if they are to sew satisfactorily, this being particularly important with synthetic threads[124]. The lubricant must provide a low and controlled level of friction regardless of the colour of the thread, and it must also protect the thread against high needle temperatures. Paraffin wax is an essential component of the lubricants used for most threads although silicones are also used since their frictional characteristics are unaffected by heat[124]. Traditionally, sewing thread lubricants were based upon organic waxes and stearates[21]. Anti-statics are also required for synthetic threads[124]. Both abrasion and yarn tension can be reduced by lubrication of the sewing thread. Lubrication also reduces needle heat to some extent[4]. All threads are lubricated during their manufacture and it should, therefore, rarely be necessary to lubricate them again at a later stage[141].

Sewing threads ought to be stored so that they stay clean and dust-free and also so that they are kept away from heat and sunlight[141]. Where the fabric has been poorly lubricated or with particularly demanding work on leather, canvas or artisan-wear, it may be necessary to lubricate the sewing thread, in which case the lubricant ought to be applied as close to the needle as possible. The best method is the use of a lubrication pack applicator, consisting of a box attached to the sewing head and containing two lubricated felt pads between which the thread passes[141]. Extra lubrication of the *sewing thread* has little effect on sewing damage since, at penetration, when damage is done, the thread is tucked away in the needle groove and has little chance to make its presence felt[3].

Additional lubricant may also react with the dye and make the thread more flammable[141]. *In-situ* lubrication of the sewing thread is regarded as one of the least satisfactory answers to sewing problems and it is advisable to obtain the advice of the sewing thread suppliers. The amount of lubricant applied to the thread during manufacturing depends upon the end-use and type of thread, with core-spun and spun polyester threads requiring more lubricant than fine continuous filament threads for instance. The type of lubricant depends upon whether the thread is synthetic or cotton[141]. At 7 000 stitches/min, silicone wax is regarded as the only sewing thread lubricant which reduces friction sufficiently to keep the needle cool[142].

6.5 Finishing of sewing threads

To help sewing threads to perform well they are given the following special finishes[114]:

1. "Soft" finish
2. Mercerisation of cotton threads
3. Bonded or glazed
4. Special finishes such as:
   a. Heat resistance
   b. Water repellency
   c. Mildew resistance
   d. Wicking resistance
   e. Anti-static
   f. Fire retardancy

For a soft finish, the thread usually has a light wax applied to control lubricity and to improve sewability. *Mercerisation* increases strength and lustre and reduces shrinkage and elongation. Gassing or singeing can increase the sheen. A *bonded* or *glazed* finish is a special process which welds the thread plies and filaments together, mostly for the leather and furniture trade[114]. For cotton *vat dyes* offer good colour fastness and are the rule not the exception. Dyeing is frequently highly automated and high colour-fastness is generally essential[124]. Package dyeing is common, with pressure dyeing necessary for synthetics.

Threads used for contrast stitching on white of light grounds should be particularly dye-fast[68]. Colour fastness tests include light fastness and resistance to sunlight, wet and dry rubbing fastness,

fastness to perspiration, washing, dry cleaning solvents and even fumes. These depend upon the particular end-use and not all threads need all the above properties. Swimwear, for example, requires threads which are fast to chlorinated water and sea-water, together with a high degree of sunlight fastness. ISO tests are generally followed. The colour-fastness of sewing threads has been discussed by FitzMaurice[143].

Relaxation during dyeing generally imparts dimensional stability to the thread and also imparts a degree of non-recoverable extension. The latter reduces to a minimum seam puckering caused by elastic recovery of the thread on release of tensions imposed upon the thread during sewing[116]. Undyed yarns should be steamed in the plied form[116].

Perspiration used to be one of the main causes for seam failure when cotton sewing threads were used, but this is no longer the case with polyester or cotton/polyester threads. Where flammability may be a problem, spun polyester threads are generally preferred to cotton or cotton/polyester[81].

6.6 Sewing thread size

Despite constant efforts towards standardisation, different systems are still in use for expressing the "size" (linear density, count, thickness, etc.) of sewing threads[144]. Generally metric counts (Nm) and the English Cotton system (Ne_B) are the most commonly used[144]. Sewing thread *size* is expressed as ticket size (refers to diameter of the thread) in cotton and as denier in synthetics[114]. However, there is a movement to the tex system[114]. If a thread is given as Nm 100/2, Ne_B 60/2 or 10 tex x 2, it implies that two threads of the indicated count have been twisted together. The same holds for three-ply threads[144].

The ticket number refers to the *diameter* of the sewing thread. All No. 70 thread should fit the same needle eye. A 70/2 thread is made from 40/2 yarn count which is equivalent to 20/1. The 70/3 thread is made from 60/3 yarn count which is also equivalent to 20/1.

For *filament* threads 10% is added to the actual thread denier due to contraction of the thread when it is twisted. The last digit is then dropped to give the ticket number, e.g.

1. No. 15 Nylon: 2 ends of 70 denier are twisted together plus 10%

   = 140 + 14 denier

   = 154 denier

   = 15

2. No. 23 nylon: 3 ends of 70 denier are twisted together (3 x 7 = 210) + 10%

= 210 + 21 denier

= 231 denier

= 23

3. No. 33 nylon : 3 ends of 100 denier are twisted together (= 300 denier) plus 30 = 330

= 33

In the U.K. it is usual to express the *ticket number* as the three ply equivalent (i.e. it is based on the assumption that the thread is a *three-ply* construction regardless of whether or not it is). For example, a *ticket* No. 60 is resultant 20's (cotton count) and could be a 2/40's, a 3/60's, a 4/80's or a 6/120's thread. With *synthetic-spun* yarns, these may be expressed as the thread size based on the *metric* or *direct* count system but still on a *three-ply* basis[77]. This means a 20's ticket would be twice as coarse as say a 40 ticket.

The ticket numbers on Coats synthetic articles (Drima-T, Drima, Koban, Aptan, Gral and Sonal) also indicate the size of the thread calculated on a 3-ply *basis but in metric* count[70]. To arrive at a 3-ply cotton thread of roughly equivalent grist, multiply the metric ticket number by 0,6. The ticket number must be divided by 3 to obtain the resultant *metric* (not *tex*) count of the thread. A core-spun 50 sewing thread is equivalent in grist to a 3-ply 30 cotton thread but has the strength of a 3 ply 18[139].

Thread thickness (size or linear density) depends upon the type and mass of the fabric, generally the heavier the fabric the coarser the thread[4]. Sewing thread thicknesses should be about 35 to 40% of the needle thickness[26]. A simple test for the correct sewing thread, thread it through a separate needle and check whether the sewing needle easily slides from one end of the sewing thread to the other when the two ends are lifted alternately[26].

Some recommendations are given in the following table[145]:

TABLE XXIX

Needle Sizes			Cotton	Mercerized Cotton	Nylon or Dacron		Denier
9	10.	11	90/3	—	15	23	
10	11	12	80/3	0000	23	30	
11	12	13	70/3	000	23	30	33
12	13	14	60/3	00	33	42	46
14	15	16	50/3	0	42	46	
16	17	18	40/3	A	42	46	69
16	17	18	36/3	A	46	69	
17	18	19	30/3	B	69	92	
18	19	20	24/3	C	69	92	99
19	20	21	20/3	D	92	99	115
20	21	22	16/3	E	99	115	138
21	22	23	12/3	F	115	138	
22	23	24	10/3	—	138	207	220

6.7 Knots in sewing threads

Cotton, spun-rayon and spun polyester sewing threads are the most commonly produced on the cotton system[146]. If such threads are sold "knotless", broken threads (in the final plied form) are joined (spliced) by an adhesive at different positions for each of the plies so that they do not overlap. Knots in individual ends are generally not removed[146].

Plied knots create problems in needle threads since they may be too large for the needle eye and they may also not slip under the tension spring on the bobbin case[146]. They are generally not a problem as far as loopers are concerned. Weaver's knots are generally used if a break occurs during the twisting operation. If a yarn breaks while it is still in singles form it is rejoined by what is termed a "chicken head" knot (so-called because its outline vaguely resembles that of a chicken head). Sometimes plies are lapped (i.e. neither joined nor knotted) so that the ends will separate when the thread is unwound from the bobbin, the thread being marked by a distinctive colour well before the broken ends so that the alert operator can stop the machine and then it is only necessary to rethread the needle and/or looper and not the whole machine. In some cases, e.g. for heavier threads, it is required that the knots be pulled to the top of the package and tied. This provides warning to the sewing operator[146].

The vast majority of core-spun threads are produced with two or three plies. Generally, thread breaks in one end is joined by a knot and a breakage in the plied thread is also repaired by a knot since it is difficult to "glue" synthetics and the cotton wrap could be distorted at the join[147].

Textile adhesives are not used to join continuous filament threads, instead a weavers knot is used for single ply knots. Plied knots are very rare in filament threads, but these are generally also weavers knots. Mechanical knotters are claimed to give inferior knots to manually tied ones and are rarely used for synthetic threads[147]. Knots in textured threads are generally pulled to the top of the package so that the machine can be stopped in time. Loopers, having much larger openings than the sewing needles, will frequently sew a knot, particularly if relatively fine sewing threads are used. It is rare, however, that a knot will sew through a sewing needle[147].

6.8 Sewing thread breaks

Needles, when hot, frequently cause synthetic threads to leave melt deposits in the needle eye which solidify when the machine stops and this results in the eye of the needle being blocked, impairing the free passage of the thread thus causing it to break[14]. Although natural fibres can also suffer damage due to high temperatures they usually break due to causes other than high needle temperatures. Thread breaks in the case of cotton sewing threads are often related to the initial impact of the upper edge of the sewing needle eye on the needle thread as the latter is forced in loop form through the fabric, the thread so damaged often breaking at a later stage in the sewing cycle. Losses in cotton sewing thread strength of from 5 to 20% have also been observed when the threads removed from the fabric were compared with the original (control), thread damage increasing as the number of fabric plies are increased. Increasing sewing speed increases thread damage; so, too, can incorrect setting of the checkspring angle which results in higher thread tensions at the instant of needle impact. The spacing between the rotary hook and the needle is also of great importance. Treated (mercerised and resin treated) cotton threads showed less fatigue resistance than untreated threads due to increases in stiffness and a deterioration in extension[14].

6.9 Testing sewing threads for sewability

Test methods for sewing threads are given by the ASTM[148]. In practice, sewing threads are often assessed by what has been termed the "snap decision", which involves the stretching of a length of sewing thread by hand until it snaps. This is essentially related to tensile strength and may lead to completely erroneous results[118]. The performance of sewing threads during sewing depends upon the interaction of the sewing machine, the thread and the fabric being sewn[149]. There appears to be no generally accepted standard method for measuring the performance of a sewing thread during sewing, although various tests have been developed for this purpose and these often differ according to the particular manufacturer. The tests can be classified into two categories, those based on monitoring the occurrence of thread breaks when sewing either[149]:

(i) a constant number of fabric plies at variable need thread tension (e.g. maximum thread tension which allows a seam of 1 metre to be sewn without thread breakage), or

(ii) a variable number of fabric plies at constant needle thread tension (e.g. maximum number of plies through which a 1 metre seam can be sewn without thread breakage.

There is also the test which assesses the reduction in strength (loop and tensile) in a thread after sewing[149]. The recovery of thread from a seam can present problems, however, with blotting paper sometimes used in place of the fabric or eliminating the use of an under thread and collecting the needle thread on a tube facilitating matters. Loss in loop strength is, however, often not correlated with loss in tensile strength, the former generally being lower. The loop strength loss is generally consider the better measure of sewing thread performance, particularly for polyester threads[149].

The variable tension and variable number of plies tests, respectively, tend to rank threads of the *same composition* in the same order but not threads differing in fibre composition[149]. Percentage loss of loop strength as an estimate of sewing damage is affected even more by the fibre composition. One of the two simulation tests (i.e. variable thread tension or variable number of plies) is considered preferable to the loss in loop strength test as a screening test when comparing an unknown thread with a thread of the *same fibre composition* and similar linear density (count).

6.10 Effect of sewing thread on needle temperature

The effect of sewing thread on needle temperature is complex[14]. The thread is able to cool the needle by conducting the heat away and by increasing convection losses due to the cooling air stream carried along by the thread. On the other hand, heat can also be generated by the thread passing through the eye of the needle at very high speeds. In the absence of cloth the thread friction at the eye can raise the needle temperature by about 50° C[14].

These opposing effects generally lead to a reduction in needle temperature when a sewing thread is introduced[14], particularly at higher temperatures. Frictional heating between needle eye and sewing thread increases with increasing thread diameter and the thread causes a larger reduction in needle temperature with small-diameter needles than with large-diameter needles. Sewing thread lubrication reduces needle temperature mainly due to the "coolant" effect of the lubricant in absorbing heat. This infers that solvent based lubricants may be preferable since the heat is removed by vaporization of the solvent[14]. Soiling of the fabric by the lubricant must, however, be avoided. Continuous filament sewing threads result in higher needle temperatures than staple fibre threads because of greater needle-to-thread friction and also because staple fibre threads transport more cooling air to the needle[14, 150]. This often enables 10% higher sewing speeds to be used for staple fibre threads compared to filament threads. Scanning electron micrographs have indicated that synthetic threads break due to a combination of thermal softening and impact tension[22].

Needle temperature has also been investigated by Nestler *et al*[150] it being shown that the equilibrium needle temperature is lower with than without sewing threads, with different types of sewing threads giving different needle temperatures when used under identical conditions.

Spun or core-spun sewing threads have surface hairs which transport cooling air to the sewing needle[26] and also part of the heat generated is carried off by the air stream which the spun thread generates. The needle temperature rises immediately the sewing thread breaks. Greater temperature variation occurs as a result of variation in thread *material* than as a result of thread *size* (thickness)[16]. Nylon was found to run almost 56°C hotter than cotton thread. Melted thread or fabric residue may have less tendency to adhere to the needle when lubricants are used. Such melted residue would otherwise build up in the eye of the needle and solidify when sewing temporarily stopped. When operation resumed thread breakage would be more likely to occur[16].

Lünenschloss and Gerundt[151, 152] found that knitted fabrics (polyester, polyester/wool and acrylic/wool), from which the yarn lubricant (paraffin wax) had been removed, always gave higher needle temperatures than fabrics still containing the lubricant. Generally, needle temperature tended to first increase with increasing number of stitches sewn until an equilibrium value was attained, although for waxed fabric and sewing without sewing thread it remained constant[152]. They also found that for *waxed material* the needle temperature increased with increasing number of fabric layers when sewing without a sewing thread while no such trend was observed when sewing thread was used. For two layers of *waxed* materials, the needle temperature was higher with sewing thread than without, whereas for three layers of fabric (waxed and unwaxed) and for two layers of *unwaxed* fabrics, the reverse was true[152]. It appears that there is a limiting temperature which determines whether the sewing thread has a heating or cooling effect on the needle. Sewing without thermal damage to the fabrics, was apparently only possible when the fabrics contained wax (applied to the yarn). It was suggested that friction between sewing thread and needle could contribute significantly to needle heat and its distribution. It also appears that at low temperatures the sewing thread has a warming effect whereas at higher temperatures it has a cooling effect. It was suggested that a rise in needle temperature with an increase in the number of fabric layers could be avoided by using waxed knitting yarn and a sewing thread[41]. With a sewing thread, the needle temperature is more evenly distributed along the needle than when no sewing thread is used in which case the maximum temperatures occur at the needle point and in the vicinity of the eye of the needle[41].

Thermoplastic fabrics can be divided into three groups, viz. 1) very fusible (e.g. polyvinyls); 2) easily fusible (e.g. polyamides) and 3) less readily fusible (e.g. polyesters, polyacrylics)[14]. The *thread* temperatures which each of the groups can withstand are approximately 80°C, 200°C and 250°C, respectively, the softening point of the fibre being of cardinal importance. Traces of fusing have been observed at a *needle* temperature of 200°C (when using polyamide, polyester and acrylic fabrics). However, much higher needle temperatures are required before the *sewing thread* breaks, these being of the order of 240°C to 260°C for polyamide (nylon), polyester and core-spun threads. Cotton and silk can withstand needle temperatures in excess of 400°C[14].

6.11 Thread Make-up

Different types of machines require different types of thread packages, e.g. small spools, cops, cones, vicops, vicones (king spools), cocoons and canisters. Pre-wound bobbins for lockstitch machines are generally made from card-board shaped like the metal spool. The two basic advantages of the pre-wound bobbin are the savings in machine operator's rewinding time and the certainty that a correct thread tension has been applied[68], it being essential that even unwinding tensions are ensured[124].

7. MISCELLANEOUS

A recent development is *Ultrasonic sewing* which involves the joining of thermoplastic materials by momentarily melting fibres in the seam area and which then becomes bounded when the material solidifies[153]. A power supply converts line current into high frequency electrical energy which is then converted into mechanical energy and which in turn is converted into heat energy. Two pieces of thermoplastic material are compressed against each other and the bottom of the horn by a pattern plate or stitching wheel. This happens 20 000 times a second and generates intense heat at the interface, causing the material to melt. Materials that can be sewn ultrasonically include polyester, polypropylene, polyethylene, PVC, polyamide (nylon) and thermoplastic coated foils and coated paper. Cotton, wool, silk, linen and other natural fibres degrade rather than melt when heated and are therefore not suitable. However, the presence of up to 35% of natural fibres in a blend with thermoplastic fibres can still be sewn in this way[153]. The most obvious advantages of ultrasonic sewing is the elimination of needles and thread along with the associated problems and, furthermore, high speeds are possible (equivalent to 7 000 rev/min at 3,9 stitches/cm and when connected to an automatic material handling system this rate can be increased quite easily[153]. Bonding instead of sewing or seaming has also been considered in another article[154].

In one study[155] the making-up properties of a wide range of fabrics has been related to their physical properties. It was concluded that easy handling in making-up can only be obtained within small ranges in tensile bending, shearing and compressional properties with a larger ratio of "plasticity" to elasticity in bending and shearing being preferable.

The traditionally used cutting room practice of stapling the marker to the lay, to hold the marker in place, can rupture yarns and leave holes sometimes mistaken for needle holes in the finished garment[29]. The use of drill holes in the garment proper should also be avoided where possible since they can also be responsible for quasi-needle cutting. Pinned tickets can also cause damage. Elsewhere it is also reported[156] that drill and pin holes are often mistaken for needle cutting. The sewing machine transport system can apparently also affect the number of faults significantly[109].

A dry atmosphere can render fabric harsh and more brittle and, therefore, more prone to sewing damage[38]. In wool and wool/polyester knitted fabrics, sewing damage was lower at 63% RH than at either 56% or 50% RH[109]. Generally the sewability (in terms of seam damage) of cotton fabrics improves with an increase in the fabric regain, whereas that of most other fabrics is not greatly affected by regain[2]. This effect is, however, not detectable by the Hatrasew apparatus (F-index) which essentially measures the internal friction of the fabric and it was, therefore, concluded that the changes in regain do not affect the internal fabric friction but rather the cotton fibre and yarn strength as reflected in the fabric bursting strength[2].

International Microcircuits Inc. has developed a new bobbin controller[157] which, it is claimed, eliminates costly reworks caused by running out of thread. The mechanism signals the operator before the bobbin thread runs out[157].

8. THE MEASUREMENT OF FABRIC SEWABILITY

It has been stated that the fabric is frequently responsible for sewing damage and if it can be identified at an early stage (before cutting) steps can be taken to treat the fabric before sewing is carried out[3]. A routine sewability test should, therefore, become part and parcel of the fabric manufacturers quality control process[158].

In the past sewing damage has often been assessed by scratching the back of the seam with a fingernail to make damaged loops apparent or else manually subjecting the seam to cyclic tension (stretch) and then assessing the damage[15]. Both these methods are subjective and therefore differ from operator to operator.

Another method involves a method for determining the needle cutting propensity of polyester knitwear[159]. A seam is sewn under standard conditions, and this is followed by stressing the seam by hand and counting the number of holes (if any) which have developed. Specific sewing conditions are listed. The yarn can also be unravelled from the fabric in the area of the seam and assessed for damage by means of a magnifying glass[15]. Seam damage has also been assessed by sewing a fabric under controlled conditions, unpicking the seam and expressing the number of broken yarns as a percentage of the total number of needle penetrations[30]. Inter-yarn frictional forces can also be assessed by measuring the maximum forces required to unravel the knitted fabric and such tests have confirmed the importance of yarn mobility within the knitted structure[15, 160]. An instrument for measuring sewing damage has also been discussed by Egbers *et al* [161].

Two instruments are on the market for the routine quality control checking of fabric sewability, namely the L & M Sewability tester and the Hatra Sew. The *L & M Sewability Tester* measures the maximum and average forces as a sewing needle penetrates the fabric. These forces in turn are related to yarn-to-yarn frictional forces, fabric tightness, etc.

Braun *et al* [103] concluded that the sewability of a fabric can be determined by measuring the needle penetration force. For woven fabrics the maximum needle penetration force is highly correlated to the energy per cycle, both increasing with increasing sewing speed, number of fabric layers, needle blade diameter and the use of bulged-eye needles[162]. Increasing needle diameter from 0,028 to 0,048 increases maximum penetration force and energy expended by a factor of about 5[14]. The frictional forces encountered by the needle when penetrating the fabric can also depend upon the elasticity of the fabric, the condition of the surface of the needle and the size of its surface[26]. So, too, is the shape of the needle important. This has led to special needles being designed.

Needle penetration force measurements are stated[3] to take account of both types of damage (mechanical and needle heat or fusion). The L & M Sewability Tester (John Godrich) relies on the observation that both needle heat and bursting (cutting) are related to the force required for the sewing needle to penetrate the fabric[34,163]. In assessing the needle penetration forces, the reaction of the fabric to the needle or to the throat plate can be measured[15]. The L & M Sewability tester measures the former. The fabric is stated to react in an identical manner to the needle and to the throat plate. It has been shown, however, that needle penetration forces increase with increasing needle diameter, sewing speed and loop density[15]. It is not the 'average' needle penetration force which matters but rather the 'threshold' or 'high' forces which matter and determine the fabric sewability[3].

Needle penetration forces can be reduced significantly by lubricating the fabric[164] while the effects of knitted fabric construction and softening on sewing are discussed in another article[165] as well.

The frictional condition of the fabric affects both mechanical damage and needle temperature, monitoring of either of the latter serves to monitor the other as well[8]. It has been reported[166] that mechanical damage at seams was found to be highly correlated with needle temperatures and that it is extremely difficult to reduce needle temperature by means of special needles, cooling jets, etc. At sewing speeds of about 4 000 stitches/min it is extremely rare to record needle temperatures below about 100° C[166].

Extraction tests on fabrics have been used as a measure of sewability but they are time consuming, do not correlate and are not all that reliable. The relationship between sewing damage and lubricant level and needle temperature is illustrated by the following two figures (Fig 11 and 12)[9]:

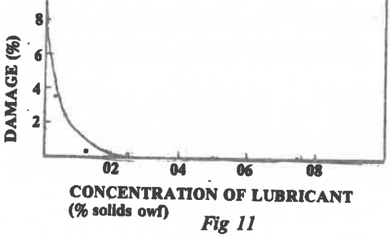


Fig 11

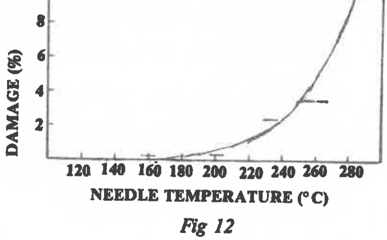


Fig 12

The *HatraSew* is fundamentally designed to monitor changes in the internal friction of fabrics as a measure of sewability[9,167]. It is used in conjunction with lockstitch or chainstitch machines usually working at speeds between 4 500 and 5 500 stitches/min and has an F-scale marked from 0 to 10[28]. The F-index is related to the needle temperature[8]. The HatraSew is manufactured under licence to Hatra and is marketed throughout the world by James H. Heald and Co. Ltd., Richmond Works, Halifax[168].

REFERENCES

1. Fortess, F., Pre-Use Testing of Fabrics, *Bobbin,* **19**, (6), 39 (Feb., 1978).
2. Parker, R. and MacCarthy, B.L., Moisture and the Sewability of Cotton Fabric, *Hatranote* No. 44 (June, 1977).
3. Anon., Sewing Damage — The Great Time and Money Waster, *Knitting World*, (2), 9 (1976).
4. Waite, D.M., Some Problems in Making-Up, *Textiles*, **2**, (1), 10 (Feb., 1973).
5. Brain, D.H., The Prediction of Strengths of Lockstitch Seams in Woven Fabrics, *J. Text. Inst.,* **61**, (10), 493 (Oct., 1970).
6. Anon., Stitches and Seams, *The Shirley Link,* 14 (Summer, 1970).
7. Friend, R.L., Sewing Room Technical Handbook, Lockstitch and Overlock Seams, Published by Hatra.
8. Tyler, D.J., Guide to Damage-Free Sewing, *Hatranote* No. 42 (Nov., 1976).
9. Tyler, D.J., Hatra Approach to the Solution of Seam Damage Problems During Making-Up, *Knit. Int.,* **82**, (978), 66 (June, 1975).
10. Leeming, C.A. and Munden, D.L., Sewability of Knitted Fabrics, *Clothing Res. J.,* **1**, (2), 41, (1973).
11. Reichman, C., Fabric Lubricants Curb Needle Cutting in Polyester Double Knits, *Knitt. Times,* **41**, (12), 34 (20th March, 1972).
12. Anon., Causes and Prevention of Needle Damage, *British Clothing Manuf.,* **12**, 35 (March, 1976).
13. Pietikäinen, I., Sewing Damage in Knitted Fabrics, *Hosiery Trade J.,* **79**, (943), 75 (July, 1972).
14. Worthington, A.P., Effect of Sewing Machine Needles in Clothing Manufacture, Literature Survey 1950-74, Shirley Institute Publication S21 (1975).
15. Anon., Damage to Knitted Fabrics Caused by the Making-Up Operation, *Hatra Translation* No. 6, (Oct., 1973).
16. Anon., Lowering Sewing Machine Needle Temperature, *Knitter,* AT 6, (5), 8 (May, 1977).

17. Hersh, S.P. and Grady, P.L., Needle Heating During High Speed Sewing, *Text. Res. J.,* **39**, (2), 101 (1969).
18. Howard, G.M. and Parsons, D., Sewing Needle Temperature, Part I: Theoretical Analysis and Experimental Methods, *Text. Res. J.,* **38**, (6), 606 (1968).
19. Howard, G.M., Sheehan, J.J., Mack, E.R. and Virgilio, D.R., Sewing Needle Temperature, Part II: The Effects of Needle Characteristics, *Text. Res. J.,* **41**, (3), 231 (1971).
20. Howard, G.M., Virgilio, D.R. and Mack, E.R., Sewing Needle Temperature, Part III: The Effect of Sewing Conditions, *Text. Res. J.,* **43**, (11), 651 (1973).
21. Brooke, C.M. and Burill, P.M., How Organo Silicone Thread Finishes Aid High Speed Sewing, *Manuf. Clothier,* **55**, (11), 59 (1974).
22. Onoue, M., Non-contact Measurement of Needle Temperature During High-Speed Sewing, *J. Japan Res. Ass. Text. End-Uses,* **17**, (6), 213 (1976).
23. Hurt, F.N. and Tyler, J., An Investigation of Needle Heating and Associated Problems in Machine Sewing, Part III: *Hatra Research Report* No. 21 (Sept., 1972).
24. Hurt, F.N. and Tyler, D.J., An Investigation of Needle Heating and Associated Problems in Machine Sewing, Part II, *Hatra Research Report* No. 20 (April, 1972).
25. Barbour Sewing Information, Bulletin No. 1.
26. Rhodes, C., Machine Needles, Part I: Stitching Problems, *Manuf. Clothier,* **57**, 60 (June, 1976).
27. Richter, K.H., Stress on Interlock Sewing Machinists Operating High Speed Machines, *Bekleidung und Maschenware,* **11**, (2), 56 (1972).
28. Anon., Heals Launch Hatra Sewability Tester for Fabrics, *Knitt. Int.,* **83**, (993), 54 (Sept., 1976).
29. Salazer, C., Needle Cutting of Knits, MascuLines, **19**, (4), 6 (Aug./Sept., 1975).
30. Hurt, F.N. and Tyler, D.J., Seam Damage in the Sewing of Knitted Fabrics, Part I: Machine Variables, *Hatra Research Report* No. 35, (May, 1975).
31. Anon., Avoiding Needle Damage in Knitted Fabrics, *Asian Text J.,* **3**, (1), 30 (Jan., 1975).
32. Kallman, R.M. and Dickert, F., How to Handle Knitted Fabrics in Fabrication, *Knitting Times,* **41**, (12), 36 (20th March, 1972).
33. Anon., Sewing Machine Feed Mechanisms, The Clothing Institute Information Sheet No. 5.
34. Blackwood, W., Sewing Needles in Knit Garment Fabrication, *Knitt. Times,* **44**, (11), 30 (17th March, 1975).

35. Escott, D., The Mechanics Guide, Part 5: Needles, Part 3, *Bobbin,* **20**, (7), 98 (March, 1979).
36. Anon., Proper Selection of Sewing Needles, *Japan Textile News,* (284), 68, (July, 1978).
37. Rhodes, C., Machine Needles, Part II: *Manuf. Clothier,* **57**, (7), 41 (July, 1976).
38. Anon., Jersey Fabric Damage: The All Important Needle, *Knitt. Int.,* **85**, (1012), 56 (April, 1978).
39. Anon., Jersey Fabric Damage — The All Important Needle, *Hosiery Trade J.,* **79**, (939), 122 (April, 1972).
40. Reichman, C., Single Knit Fabric Presents No Major Cutting Sewing Problems, *Knitt. Times,* **46**, (3), 21 (17th Jan., 1977).
41. Innes, R., West German Research into Damage due to Needle Heat, *Knitt. Int.,* **86**, (1021), 42 (Jan., 1979).
42. Dutton, W.A., Aspects of Quality Control in Making-Up, *Knitt. Int.,* **85**, (1016), 66 (Aug., 1978).
43. Leeming, C.A., Private Communication.
44. A Guide to Singer Needles, Catalogue Numbers and Price Groups, No. 670, Singer Sewing Machines Co. Ltd., U.K.
45. Mendel, A.R., New Pfaff Technology for Sewing Knit Fabrics, *Knitt. Times,* **47**, (47), 22 (Nov. 13, 1978).
46. Anon., Techniques and Equipment for Sewing Knitted Fabrics, *Knitt. Times,* **44**, (11), 33 (March 17, 1975).
47. Braun, M., Influence of the Sewing Needle Geometry on the Sewability of Knitgoods, *Melliand Textilberichte,* **58**, (9), 734, (1977).
48. Wardman, B. Handling Cutting and Sewing Knitted Fabrics, *Knitt. Int.,* **84**, (998), 48 (Feb., 1977).
49. Jung, M.A., Sewing of Knits: Basic Parameters, *Knitt. Times Yearbook,* **45**, (18), 141 (1976).
50. Anon., Guide to Primary Knitwear Sewing Stitches, *Knitt. Times Yearbook,* **46**, (18), 169 (1977).
51. Anon., Some Facts About Stitches and Seams, The Clothing Institute Information Sheet No. 4.
52. Escott, D., The Mechanics Guide: Stitches, Seams and Stitchings, *Bobbin,* **20**, (2), 84 (Oct., 1978).
53. Worthington, A.P., A Survey of Literature on Stitches and Seams for Garments, 1950 — 1974, Shirley Institute Publication S22 (1975).
54. Blackwood, W.J. and Chamberlain, N.H., The Strength of Seams in Knitted Fabrics, Clothing Institute Technological Report No. 22 (1970).
55. Schierbaum, W., Doppelsteppstich-Doppelkettenstich: Nahtbild-

Nahtkosten- Nahtwirtschaftlichkeit, *Wirkerei- und Strickerei-Technik,* **25**, (11), 64 (1975).
56. Anon., Comparison of Lockstitch and Double-Locked Chainstitch, *Readywear,* (3), 6 (1978).
57. Anon., Safety Stitch Seaming Gains Acceptance, *Asian Textile Manufacturing,* **3**, (10), 32 (Nov., 1975).
58. Rhodes, C., Sewing Threads, Part II: *Manuf. Clothier,* **57**, (4), 65 (April, 1976).
59. Callan, E.J. and Goodman, A., Avoiding Seam Cracking in Apparel Cut and Sewn of Knitted Fabric, *Knitt. Times,* **46**, (13), 23 (March 28, 1977).
60. Pollock, V.A., Clothing Workshops, *S.A. Textiles,* **23**, (7), 19 (July, 1974).
61. Anon., New Aid to Reduce Puckering Risks, *Readywear,* (3), 10 (1978).
62. Schaffer, P., Overcoming Seaming Problems on Synthetic Knit Fabrics, *Knitt. Times,* **45**, (2), 22 (Jan. 12, 1976).
63. Anon., Seam Pucker, *Readywear,* IV, 174 (Aug., 1975).
64. Moll, P., Mosinski, E. and Krowatschek, F., Investigations into the Regularity of Sewing Machine Transport Systems, *Bekleidung und Wäsche,* **24**, (1), 13 and (2), 96 (1972).
65. Fitzmaurice, J.C., Sewing Thread for Knitted Apparel, *Knitt. Times,* **45**, (51), 38 (Dec. 13, 1976).
66. Anon., A New Meter and Why, *Knitt. Int.,* **82**, (983), 86 (Nov. 1975).
67. Anon., Instant Analysis of Sewing Thread Tensions, *Wool Record,* **130**, (3381), 55 (July, 1976).
68. Rhodes, C., Sewing Threads, Part I; *Manuf. Clothier,* **57**, (3), 49 (March, 1976).
69. Anon., Needle Damage in Knitted Fabrics, The Clothing Institute Information Sheet No. 2.
70. From Staple to Stitch, Thread Advisory Service, J & P Coats (Glasgow).
71. Fitzmaurice, J.C., Sewing Thread for Knits, Part 3, *Knitting Times,* **46**, (13), 21 (March 28, 1977).
72. Anon., Pucker: Its Causes and Cures Using Synthetic Threads, *Bobbin,* **13**, (1), 66 (Sept., 1971).
73. Morris, P.A. and Brain, D.H., Seam Slippage — Letter to the Editor, *Clothing Res. J.,* **3**, (3), 135 (1975).
74. Crook, A., The Determination of Seam Slippage: A New Method, *Text. Ind.,* **8**, (10), 294 (Oct., 1976).
75. Anon., Recommended Procedure for the Determination of the Slippage

Resistance of Yarns in Woven Fabrics: Seam Method, *Text. Inst. Ind.*, **8**, (10), 297 (Oct., 1976).
76. Anon., Simple Device to Check Yarn Slippage at Seams, *Indian Text. J.*, **85**, (10), 91 (July, 1975).
77. Blackwood, W., The Role of Sewing Threads in Knitted Garment Assembly, *Knitt. Times*, **44**, (2), 24 (Jan. 13, 1975).
78. Blackwood, W.J. and Munden, D.L., Factors Affecting the Breaking Characteristics of Three-Thread Overlock Seams, *Clothing Res. J.*, **4**, (1), 3 (1976).
79. Hurt, F.N. and Parker, R., Seam Geometry in Knitted Fabrics, Part I: The Lockstitch Seam, *Hatra Research Report* No. 34 (March, 1975).
80. Hurt, F.N. and Parker, R., Seam Geometry in Knitted Fabrics, Part III: The Single-Thread Chain Stitch Seam, *Hatra Research Report* No. 41 (June, 1976).
81. Brain, D.H., Threads and Seams for Knitted Fabrics, *Clothing Inst. J.*, **26**, (3), 165 (May-June, 1978).
82. Shimazaki, K., Study on the Seam Strength of Fabrics — Effect of the Loop Strength of Sewing Thread and the Number of Stitches on the Seam Strength, *J. Japan Res. Ass. Text. End-Uses*, **17**, 414 (1976 — 11).
83. Gardner, F.F., Burtonwood, B. and Munden, D.L., The Effect of the Angle of Bias and Other Related Parameters on Seam Strength of Woven Fabrics, *Clothing Res. J.*, **6**, (3), 130 (1978).
84. Wardman, B., Making-Up Topics, *Knitt. Int.*, **81**, (8), 89 (Aug. 1974).
85. Anon., How to Sew Fine-Cut Double Jersey, *Japan Textile News*, No. 250, 101 (Sept., 1975).
86. Reichman, C., Basic Attributes Make Overedger Most Desirable Sewing Unit for Sweaters, *Knitt. Times*, **46**, (35), 7 (Aug. 22, 1977).
87. Hurt, F.N. and Parker, R., Seam Geometry in Knitted Fabrics, Part II: The Two-Thread Chainstitch Seam, *Hatra Research Report* No. 37 (1975).
88. Reichman, C., Basic Tips on Sewing Sueded and Velour Knitted Apparel, *Knitt. Times*, **45**, (32), 17 (Aug. 2, 1976).
89. Reichman, C., Fabric Lubricants Curb Needle Cutting in Polyester Double Knits, *Knitt. Times*, **41**, (12), 34 (March 20, 1972).
90. Furumatsu, Y. and Yamagi, K., Study on Sewing Quality of Jersey Fabrics in Domestic Sewing, Part I: Sewing of Polyester Jersey Seams, *J. Japan Res. Ass. Text. End-Uses*, **16**, (3), 77 (1975).
91. Anon., Making-Up and Finishing Knitted Garments, *Asian Text. J.*, **3**, (6), 15 (June, 1975).
92. Hurt., F.N. and Tyler, D.J., Seam Damage in the Sewing of Knitted Fabrics, Part II: Material Variables, *Hatra Research Report* No. 36 (Aug., 1975).

93. Anon., Silicone Wax for Needle Lubrication, *Text. Inst. Ind.,* **16,** (5), 106 (May, 1978).
94. Leeming, C.A. and Munden, D.L., Sewability of Knitted Fabrics, *Clothing Res. J.,* **1,** (2), 41 (1973).
95. Kojima, M., What is Demanded for Cloth from the Aspect of Making-Up, *Japan Textile News,* (278), 66 (Jan., 1978).
96. Atkinson, R., Specialisation of Sewing Mehods in the Make-Up of Knitted Garments, Part I: *Knitt. Int.,* **85,** 1018, 85 (Oct., 1978), Part II: *Knitt. Int.,* **85,** (1020), 57 (Dec., 1978).
97. Waesterberg, L., Making-Up Properties of Wool Fabrics, *J. Text. Inst.,* **56,** (10), T517, (Oct., 1965).
98. Wignall, H., Aids to Sewing and Seaming of Knitted Garments: A Review, *Knitt. Times,* **46,** (20), 23, (May 9, 1977).
99. Lewis, J., Ausrüstungsverfahren zur Verhütung von Maschenspreng-schäden bei Doppeljerseystoffen aus Wolle und Wolle/Synthese fasermischungen, *Textilvered.,* **12** (4), 156 (1977).
100. Anon., Garment Assembly Equipment and Sewing Threads for Knitted Goods, *Knitt. Int.,* **86,** (1022), 75 (Feb., 1979).
101. Dutton, W.A., How Dyers can Help the Maker-Up, *Knitt. World,* **(5),** 16 (1978).
102. Anon., Resumé of Research, *Knitt. Int.,* **82,** (974), 87 (Feb., 1975).
103. Braun, M., Bühler, G., Egbers, G., Mavely, J. and Ring, W., Influence of Yarn Lubrication on the Knitting and Sewing Performance, *Mell. Textilberich. Int.,* **56,** (4), 293 (1975).
104. Pietkäinen, I., The Causes of Sewing Damage in Interlock Fabrics, Valtion Teknillinen Tutkimuslaitos, Helsinki (1970).
105. Hurt, F.N. and Tyler, D.J., An Investigation of Needle Heating and Associated Problems in Machine Sewing, Part I: *Hatra Research Report* No. 19 (Nov., 1971).
106. Hurt, F.N., Instrumentation for Quality Control in Knitting, *Text. Inst. Ind.,* **16,** (5), 120 (May, 1978).
107. Rieser, W., Influence of the Construction and Softening of Knitted Fabrics with Special Emphasis on Sewability, *Mell. Textilberich. Int.,* **55,** (9), 778 (1974).
108. Tyler, D.J. Laddering in Knitted Fabrics — Some Considerations for the Finisher and Maker-Up, *Hatra Note* No. 39 (April, 1975).
109. Reiser, W., Is Loop Damage During the Making-Up of Jersey Knitted Fabrics Conditioned by their Structure, *Bekleidung und Wäsche,* **24,** (9), 637 (1972).
110. Anon., Sewing Lubricant, *Int. Dyer,* **153,** (7), 366 (April 4, 1975).

111. Finnigan, J.A., Snagging and Stitch Damage, *Hosiery Trade J.,* **80,** (950), 77 (Feb., 1973).
112. Anon., History- Manufacture and Processing of Sewing Threads, *Readywear Yearbook,* Part 2, 8 (1978).
113. Dmitrovskaya, L.G. and Varkovetskü, M.M., Determination of the Relative Importance of the Properties of Sewing Threads, *Tekstil'naya Promyshlennost,* **37,** (6), 73 (1977).
114. Cauble, S.M., Sewing Threads, Part I: *Ind. Fabrics Products. Rev.,* **53,** 16 (Apr., 1977).
115. Bennet, C. and Gibson, L.J., Fluid Beds for the Heat Treatment of Sewing Threads, Fourth Shirley Inst. Sem., "New Yarns in the Textile Scene", The Hague (Oct., 1971).
116. Sivaraman. C., Impact of Synthetic Fibres in Sewing Thread Technology, *Synthetic Fibres,* **6,** 6 (Oct./Dec., 1977).
117. Fitsmaurice, J.L., Sewing Threads for Knits, Part 4, *Knitt. Times,* **46,** (20), 16 (May 9, 1977).
118. Goosen, F.A., The Snap Decision — The Basis of Meaningful Quality Assessment in Sewing Thread Manufacture and Usage., Symp. Quality Ass. Modern Text. (Aug., 1974)
119. Cauble, S.M., Sewing Threads, Part II: *Ind. Fabric Products Rev.,* **54,** 40 (May, 1977).
120. Fitzmaurice, J.C., Sewing Thread for Knits, Part 7: *Knitt. Times,* **46,** (35), 16 (Aug. 22, 1977).
121. Anon., The Question of Thread Quality, *S.A. Textiles,* **23,** (3), 34 (May, 1974).
122. Anon, An Advance in Accurate Thread Measurement, *Hos. Trade J.,* **79,** (940), 112 (April, 1972).
123. Hanby, D.S., The American Cotton Handbook, Third Edition, Volume 1, (June, 1965).
124. Crook, A., Sewing Threads, *Textiles,* **2,** (3), 66 (Oct., 1973).
125. Anon., Recent Movement of Japanese Synthetic Sewing Thread, *Japan Text. News,* (238), 83 (Sept. 1974).
126. Anon., A Guide to Sewing Threads for Apparel, Clothing Institute Information Sheet No. 1.
127. Shimazaki, K., Studies on Machine Sewing: Influence of Machine Sewing on Cotton Sewing Thread, *J. Japan Res. Ass. Text. End-Uses,* **19,** (3), 116 (1978).
128. Wagner, C.D. and Fries, W., Modernes Nähgarn aus Chemiefasern, *Textilbetrieb,* **94,** (11), 27 (Nov., 1976).
129. Anon., "Terylene" Sewing Threads, Terylene for Industrial Uses, Edition 1.

130. Wagner, C.D. and Fries, W., Modernes Nähgarn aus Chemiefasern, *Textilbetrieb* **94**, (12), 51 (Dec. 1976).
131. Fitzmaurice, J.C., Sewing Thread for Knits, Part 2, *Knitt. Times,* **46**, (3), 28 (Jan. 17, 1977).
132. Anon., New Translucent Sewing Thread Cuts In-Plant Inventory Needs, *Knitt. Times,* **47**, (7), 20, (Feb. 13, 1978).
133. Webb, W., Monofilaments: A Generation Later, *Bobbin,* **19**, (9), 156 (May, 1978).
134. Crook, A., Fils A Condre Industriéls en Filaments de Polyester, *l'Industrie Textile,* (1078), 289 (May, 1978).
135. Wardman, B., A Star is Born, *Knitt. Int.,* **84**, (999), 103 (May, 1977).
136. Anon., Response to Thread, *Bobbin,* **20**, (6), 22 (Feb., 1979).
137. Anon., Right to the Core, *Br. Clothing Manuf.,* **XIV**, (3), 26 (March, 1978).
138. Fitzmaurice, J.C., Sewing Threads for Knits, Part 6, *Knitt. Times,* **46**, (31), 20 (July 25, 1977).
139. Anon., Jeans Means Seams of High Quality, *Asian Text. Manuf.,* **3**, (7), 42 (July/Aug., 1975).
140. Jakes, K.A., Schneider, E.F., Smith, B.F. and Spinak, S.M., Factors Affecting Seam Flammability, *Text. Chem. Col.,* **6**, (3), 24/53 (1974).
141. Anon, Lubricating Sewing Threads — Why and When to do it, *Asian Text. Manuf.,* **3**, (8), 43 (Sept., 1978).
142. Anon., Silicone Wax Solves Needle Heat Problem, *Knitt. Int.,* **85**, (1013), 91 (May, 1978).
143. Fitzmaurice, J.C., Sewing Thread for Knits, Part 5, *Knitt. Times,* **46**, (24), 20 (June 6, 1977).
144. Anon., Sewing Thread Counts, *Readywear Yearbook*, Part 2, 8 (1978).
145. Anon., Overcoming Needle Cutting in Sewing Textured Polyester Double Knits, *Knitt. Times,* **42**, (31), 22 (July 23, 1973).
146. Yowell, E., Knots in Industrial Sewing Threads, *Bobbin,* **1**, (2), 78 (April, 1977).
147. Yowell, E., Knots in Industrial Sewing Threads, *Bobbin,* **1**, (12), 72 (May, 1977).
148. ASTM Annual Book of Standards.
149. Mo, E.S. and Frank, T.F.P., The Testing of Sewing Threads for Sewability, *Clothing Res. J.,* **5**, (1), 35 (1977).
150. Nestler, P., Arnold, J. and Trache, A., Investigation of the Thermal Behaviour of Sewing Machine Needles During Sewing, *Textiltechnik,* **25**, (3), 179 (1975).
151. Lünenschloss, J., Einfluss der Paraffienierung auf die Nähnadel-

temperatur beim Nähen von Maschenware, *Melliand Textilberich,* **59**, (9), 730 (1978).
152. Lünenschloss, J. and Gerundt, S., Waxing and Heating, *Text. Asia,* **10**, (1), 38 (Jan., 1979).
153. Parteino, A., Sewing Accross the Sound Barrier, *Knitt. Times,* **47**, (51), 28 (Dec. 11, 1978).
154. Anon., Bonding Instead of Sewing and Seaming, *Int. Text. Bull., Dyeing/Printing/Finishing,* (2), 188 (1977).
155. Morooka, H. and Niwa, M., Physical Properties of Fabrics Relating to Making-Up and Good Appearance, *J. Text. Mach. Soc. Japan,* **24**, (4), 105 (1978).
156. Anon., Effects of Needle Cutting on Fabric, *Modern Knitt. Man.,* **55**, (5), 31 (Sept./Oct., 1977).
157. Anon., IM Produces new Bobbin Controller, *Knitt. Times,* **47**, (47), 48 (Nov. 13, 1978).
158. Dick, A.L. and McDonald, R., Fabric Lubrication, *J. Soc. Dyers Colorist,* **94**, (6), 264 (June, 1978).
159. Spain, R.E., Test Method for Needle Cutting in Polyester Knitwear, *Knitt. Times,* **40**, (50), 44 (Dec. 6, 1971).
160. Anon., Damage to Knitted Fabrics During Making-Up, *Bull. Scientifique de l'Institut Textile de France,* **2**, (6), 137 (1973).
161. Egbers, G., Braun, M. and Ring, W., Die Ermitthung von Nähschäden an Jersey mit einem Prüfgerät, *Wirkerei- und Strickerei-Technik,* **25**, (4), 199 (April, 1975).
162. Kamata, Y., Tsunematsu, R., Kinoshita, R. and Naka, S., Needle Fabric Interaction during Sewing, *Sen-i Gakkaishi,* **33**, (4), T157 (1977).
163. Leeming, C.A. and Munden, D.L., Investigations into the Factors Affecting the Penetration Force of a Sewing Needle in a Knitted Fabric and its Relationship with Fabric Sewability, *Clothing Res. J.,* **6**, (3), 91 (1978).
164. Anon., Influence of Lubricating Knitted Goods on the Needle Penetration Forces During Sewing, *Textil Praxis Int.,* **29**, (7), 917 (1974).
165. Rieser, W., Influence of the Construction and Softening of Knitted Fabrics with Special Emphasis on Sewability, *Melliand Textilberichte,* **55**, (9), 778 (1974).
166. Hurt, F.N. and Tyler D.J., Sewing Damage and Quality Control Tests for Fabrics, *Knitt. World,* (3), 30 (1976).
167. Tyler, D.J., The Hatra Sewability Tester, *Hatranote* No. 40.
168. Anon., New Approach to Fabric Sewability Testing, *Wool Record,* **130**, (3382), 49 (Aug. 1976).