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To cite this article: M S Masete *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **430** 012015

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The effect of specimen geometry on tensile properties of titanium alloy metal sheet.

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Abstract. Determination of tensile properties of materials is required to reliably predict performance of engineering materials in service and for design purposes. Tensile properties are also used as a measure of product quality. Various testing standards recommend specific specimen sizes for reporting of tensile properties. This recommendation is normally a challenge in materials development where the required specimen size is not achievable due to component size limitation. In addition, the materials developer still wants to compare their tensile results with the reference materials produced from standard sizes or produced from different geometries. It is well documented that tensile properties are affected by the specimen geometry (gauge length and cross sectional area). It is therefore the purpose of this study to investigate the effect of specimen geometry on tensile properties. In addition, this study seeks to determine suitable specimen geometry required to yield comparable tensile properties obtained from other specimen geometries. Various dog bone specimen geometries were produced from a titanium alloy metal sheet and tensile properties determined. Yield strength, Ultimate tensile strength and, % elongation were compared. Yield strength and ultimate tensile strength were not affected by different specimen geometries. However, % elongation differed for different geometries.

1. Introduction

It is common practice during development of engineering materials to determine tensile properties. These properties are required to qualify materials, predict performance and sometimes improve on properties of currently available materials.

Even though determination of tensile properties is well known, certain considerations need to be adhered to for the results to be acceptable. Various testing codes prescribes geometries and test conditions in order for the results to be valid and comparable. During material development, one normally seeks to compares the new results with the existing ones to determine if improvement has been achieved or not. Various testing standards and authorities [1][2] allow such comparison only if all the conditions are similar i.e. same testing conditions and same sized specimens. The ISO 6892-1 standard [1] prescribes a gauge length of either 50 mm or 80 mm while ASTM E8 standard [2] prescribes a gauge length of 25 mm, 50 mm or 200 mm for tensile properties evaluation. In addition both standards [1][2] require that the gauge length to width ratio (L/W) be either 4 or 5. The specimen geometry is reported to have negligible effect on the Yield Strength (YS), Ultimate Tensile Strength (UTS) and Young's modulus, while ductility is greatly affected [1][2]. The ASTM E8 standard [2] suggests keeping the gauge length over square root of area (L/\sqrt{A}), the same to reduce the effect of



specimen geometry on ductility while ISO 6892-1 [1] suggest the gauge length over width (L/W) to be constant. Depending on material availability, prescribed specimen sizes are often not achievable. This would then imply that the material developer cannot confidently compare the new tensile results with the known one.

Various studies have been carried out to try and address this difficulty [3–6]. Han et al [3] compared tensile properties of either steel or aluminium alloys for plate type specimens having different gauge length and width. The results showed that YS, UTS and Young's modulus were not affected by the change in specimen geometry. However, % elongation (% EL) differed by around 10% for different gauge lengths. Even though Han et al [3] showed that % EL was greatly affected by specimen geometry, there was no suggestion on how this problem could be overcome if one wants to compare % EL of differently sized specimens. Strnadel and Brumek [6] kept the L/\sqrt{A} the same and equal to about 5.56 to remain compliant with the standards. The results showed that ductility (% EL) decrease with increasing cross sectional area. However, the authors [6] did not show whether keeping the L/\sqrt{A} equal to 5.56 reduced the effect of specimen geometry on % EL. Yuan et al [5] used a specimen with a gauge length of 25 mm and width of 6 mm as specified by the ASTM E8 standard [2] to investigate the effect of specimen thickness on tensile properties. As Yuan et al [5] increased the specimen thickness, the L/\sqrt{A} reduced leading to an increase in % EL. The YS and UTS were not affected by the change in thickness. The ASTM E8 standard [2] gives no exact requirement for thickness of plate specimens hence a study by Yuan et al [5]. Al-bakri et al [4] also found that for specimens with similar gauge length and width, as thickness increases, ductility increases.

Literature agree that specimen geometry affects tensile properties especially % EL. Various considerations such as keeping the L/W equal to 5, keeping the L/\sqrt{A} similar, and having a gauge length of at least 25 mm, were put forward in ensuring that tensile properties are in compliant with the standards. However, none of the studies clearly showed how one can design a sub-size specimen to ensure similarity of tensile properties especially % EL. The question that is not answered is whether the L/W ratio of about 4 to 5 is a must for compliancy. In addition, can one get similar tensile properties from specimens with gauge length much smaller than 25 mm? The purpose of this study was then to investigate the effect of specimen geometry (gauge length, specimen width, specimen thickness) on tensile properties of plate type specimen. In addition, the aim of the study was to propose suitable geometries required to compare with tensile properties obtained from specimens of other sized plate specimens. The results of this study would be beneficial to material developers that use non-standard and sub-size specimens to confidently compare their tensile results to those of other researchers using completely different geometries.

2. Experimental procedure

2.1. Materials

The Ti-6Al-4V alloy metal sheet 1.1 mm thick was used for this study. Electric discharge machining was used to cut tensile specimens of various geometries indicated in Table 1. Geometry A and B were cut to have different gauge length over area ratio (L/\sqrt{A}), while geometry C and D were cut directly according to ASTM E8 standard [2]. It should be noted that ASTM E8 standard [2] kept only the L/W ratio the same for geometry C and D. All specimens were cut parallel to the rolling direction as shown in Figure 1.

Table 1. Dimension of specimens tested.

	Gauge length	Width	L/\sqrt{A}	L/W	Total length
Geometry A	18	2.5	10.9	7.2	40
Geometry B	27	2.5	16.3	10	50

Geometry C	32	6.25	12.2	5.12	62
Geometry D	60	12.5	16.2	4	200

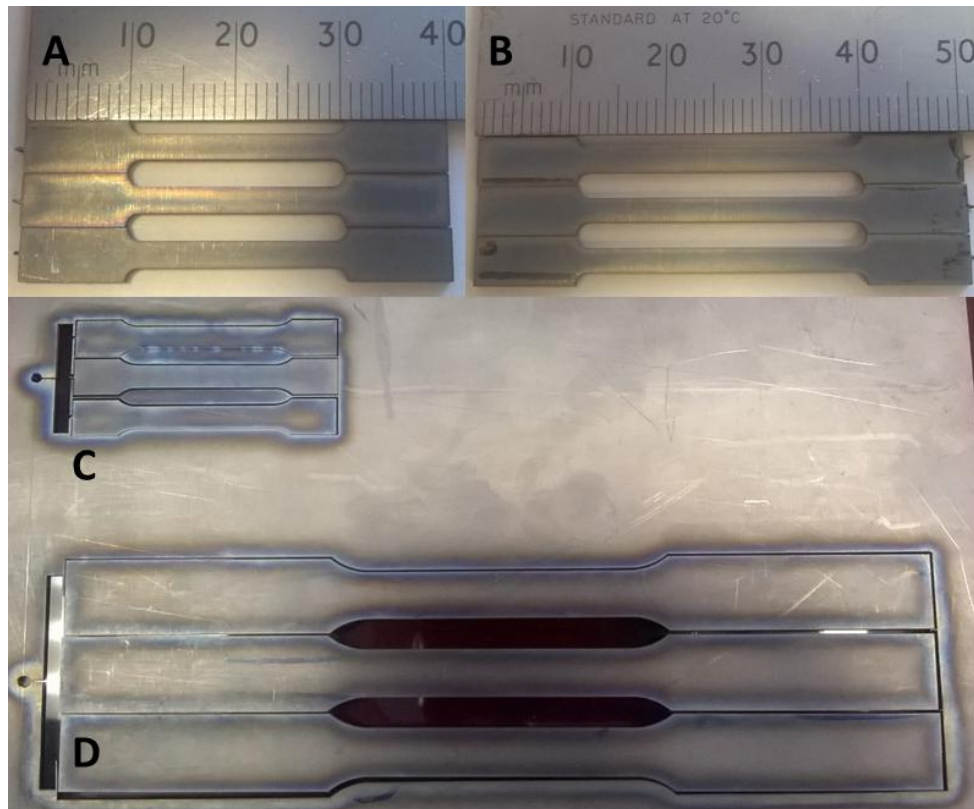


Figure 1. Specimens (Geometries A to D) used for tensile testing.

2.2. Tensile testing

An InstronTM 1342 tensile tester fitted with a 50 kN load cell was used to perform tensile tests at room temperature and at a constant crosshead speed of 0.5 mm/min. The tensile strain was measured using an extensometer attached to the gauge section of the test specimen. The extensometer was then removed at a strain of 1.5% to prevent damage during specimen fracture. Testing continued until the specimen fractured. Three specimens were tested for each geometry type. The 0.2 % YS and UTS were automatically determined by the Bluehill 2 software after testing. The gauge length of the specimen was measured before and after testing to calculate the % EL.

3. Results and discussion

Table 2 shows tensile properties of the geometries tested.

The change in YS from the lowest value (geometry D) to the highest value (geometry A or B) is 2 %. This change shows that there were no significant differences between the YS of all the geometries tested. Therefore, the change in gauge length or gauge area did not influence YS. Similarly, UTS increased by 3 % from geometry D to geometry A. Therefore, UTS was not significantly influenced by the change in specimen geometry. These results are consistent with those reported from literature that specimen geometry has a negligible effect of YS and UTS [3–6].

There was a 20 % increase in the value of % EL from the lowest value (geometry D) to the highest value (geometry A). Therefore, specimen geometry had a significant influence on % EL. However,

specimens having similar L/\sqrt{A} ratio (geometry B and D) had % EL values differing by 6 % which is lower than the 10 % normally accepted as a significant change for destructive tests. In addition, Figure 2 shows that geometry B and D had overlapping error bars indicating that the % EL values were not significantly different.

Table 2. Tensile properties.

	(L/\sqrt{A})	YS (MPa)	UTS (MPa)	% EL
Geometry A	10.9	969±2	1040±20	14.1±0.7
Geometry B	16.3	969±0	1039±3	12.2±1.0
Geometry C	12.2	964±6	1024±6	13.1±0.8
Geometry D	16.2	953±3	1012±9	11.4±0.2

Geometry C was a direct sub-size of geometry D as prescribed by ASTM E8 standard [2] but the % EL varied by 14 %. The error bars of geometry C and D were not overlapping indicating significantly different % EL values. This indicates that similar L/\sqrt{A} ratio leads to similar % EL values than similar L/W ratio. Therefore the L/W ratio used by ASTM E8 standard [2] to decide on sub-size specimen geometry D relative to geometry C was not appropriate if one wants to compare % EL of differently sized specimens. However, ASTM E8 standard [2] still warns about the need for the L/\sqrt{A} to be kept similar. Therefore, it has been established in this article that one cannot always keep both the L/W ratio and L/\sqrt{A} ratio the same for the plate type specimens. This consideration becomes even more challenging when the resultant specimen thickness cannot be varied at will.

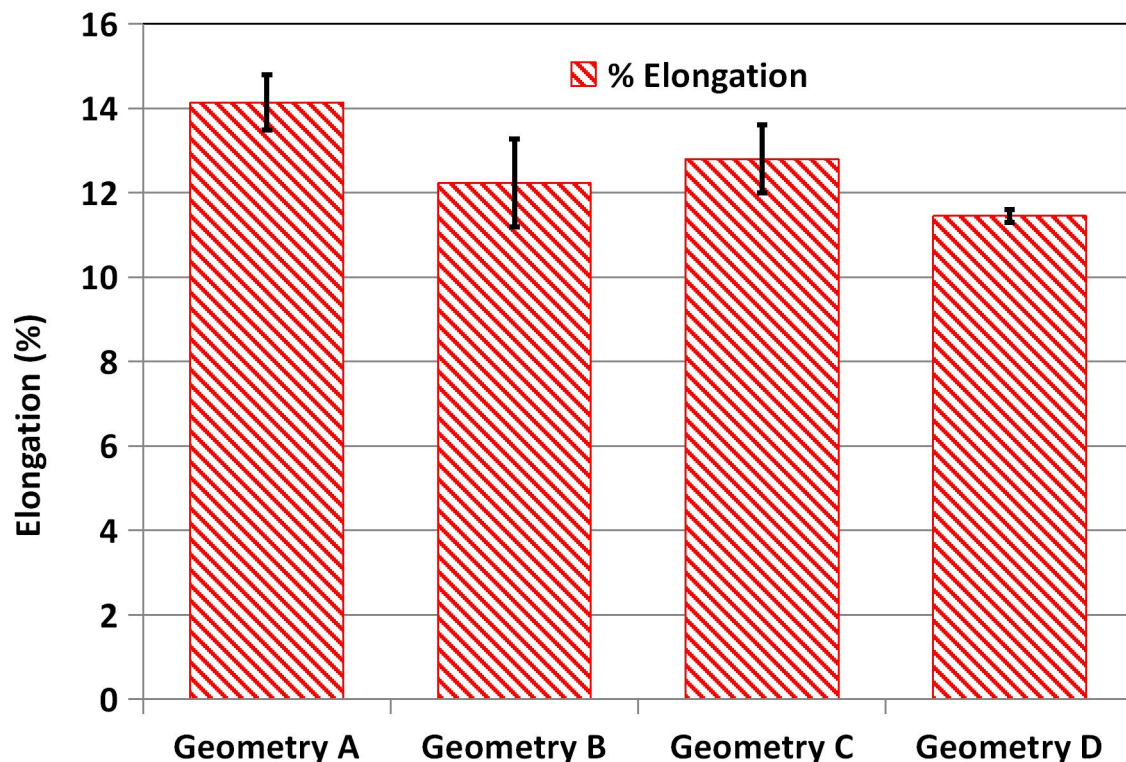


Figure 2. % Elongation for various specimen geometries.

Consistent with the literature [2][4][5], the lower the value of the L/\sqrt{A} ratio, the greater the % EL as shown in Figure 2.

The results of the current study showed that the L/\sqrt{A} has the most influence on determining similarity of tensile properties than the L/W ratio. This implies that one can use sub-size specimens and still get tensile results comparable to larger conventional standard specimens. Therefore, one can design specimens with comparable tensile properties as long as the dimensions of the reference specimens are known and the L/\sqrt{A} is kept constant.

4. Conclusions

The following conclusions were drawn from tensile testing of plate type specimens with different geometries:

- Yield strength and ultimate tensile strength were not significantly affected.
- Keeping the L/W the same was not adequate to yield similar percentage elongation values.
- Similar L/\sqrt{A} produced similar percentage elongation values.
- Tensile properties of specimens with different geometries can be compared by keeping their L/\sqrt{A} the same.

Acknowledgements

The authors wish to acknowledge the South African Department of Science and Technology (DST) and the Council for Scientific and Industrial Research (CSIR) for sponsoring this study. The assistance of Chris McDuling during tensile testing is greatly appreciated and Martin Williams for his advice in specimen design.

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