

REDUCING NON VALUE ADDING ALUMINIUM ALLOY IN PRODUCTION OF PARTS THROUGH HIGH PRESSURE DIE CASTING

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Abstract

The difficulties and issues associated with the economics of the process and die life in casting Aluminium alloys, as experienced by the high pressure die casting industry, were reasons behind undertaking this research project. The use of a tungsten alloy able to withstand high temperature process conditions without the welding problems experienced by standard die construction materials, such as H13, was examined in an extensive series of casting trials. The importance of operating dies at elevated temperatures to minimize heat checking has been demonstrated previously, both through theoretical thermal modelling and experimentation [1]. This paper describes both aspects of die life extension and possibilities to reduce the amount of alloy material used in the cast part feed system, including overflows. CSIR intends using the results of this research for further development and application of high temperature die construction materials in high pressure die casting processes of light metal alloys.

Keywords: High Pressure Die Casting, Die Manufacture, Die Life, Thermal Fatigue, Light Metal Alloys.

1. INTRODUCTION

One of the biggest challenges when using the high pressure die casting (HPDC) process is to overcome product porosity. There are two types of porosity, namely gas porosity (caused by melt flow turbulence) and shrink porosity (caused by insufficient intensification or feeding of material into hot spot areas that are cooling at a slower rate). One of the single biggest causes of porosity is the incorrect design of the die feeding system (runner and gate). A lot of development, design and experimentation have been done in an attempt to address this problem. When designing the feeding system for a die there are certain important criteria to adhere to, such as the location and size of the gate, the quality and wall thickness of the part and the volume of the part. This, combined with the geometry of the part, can result in a feeding system with multiple supply channels or runners. These runners need to be of a certain magnitude to allow for the melt to fill the cavity and can become long and bulky (require more material) depending on the geometry and specifications of the part. All the factors above are crucial for the runner design process and can be considered as points of departure. However, to be able to reduce the volume of the runner, one must have a clear understanding of what happens to the melt in runners.

During conventional cold chamber HPDC conditions, the melt, an Aluminium alloy, enters the runner at approximately 630°C and comes in contact with runner surfaces which are at about 200°C. A solid metal skin is formed on the runner surface leaving the core still liquid. The solid skin will continuously increase in thickness and the liquid core decrease in size. This all happens within fractions of a second (0.01 - 0.015 s). This is one of the main reasons why runners are so bulky for HPDC; it is to ensure that the runner does not freeze off at the gate before the cavity is properly filled. To enable one to reduce the size of the runner the solid skin that forms on the runner surface must be greatly reduced or eliminated. This can only be done by heating the runner area to approximately the same temperature as the melt and will require special materials and heating cartridges able to operate at higher operating temperatures, i.e. from 300 to 600°C. By doing this, other problems are created such as heat transfer into the cavity, which will increase the melt temperature and subsequently increase the cycle time. This will soften the cavity inserts normally manufactured from H13 steel and increase problems due to heat checking and wetting, especially when processing aluminium. To overcome these problems the inserts that are exposed to the high temperature must be insulated from the rest of the die cavity [1].

2. EXPERIMENTAL APPROACH

2.1 Test Die

A die with multi temperature zones was designed and manufactured [1] incorporating inserts made of Anviloy 1150, a high temperature alloy, in the runner area. The die design was of a modular approach which makes provision for replaceable inserts in the runner and biscuit area. These inserts were manufactured from standard hot work steels and special heat resistant materials where a volume reduced runner design was incorporated in the latter. The objective was to maintain the same part quality as produced with standard HPDC process conditions. Proper insulating and heating methods were implemented in the die design to ensure the proper HPDC process conditions were achieved.

A graphic representation of the component used on the experimental die can be seen in Fig1 bellow.

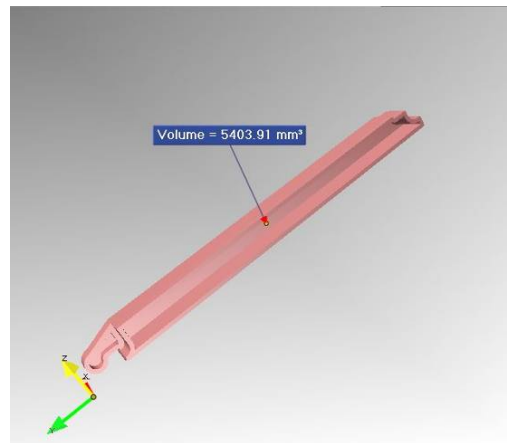
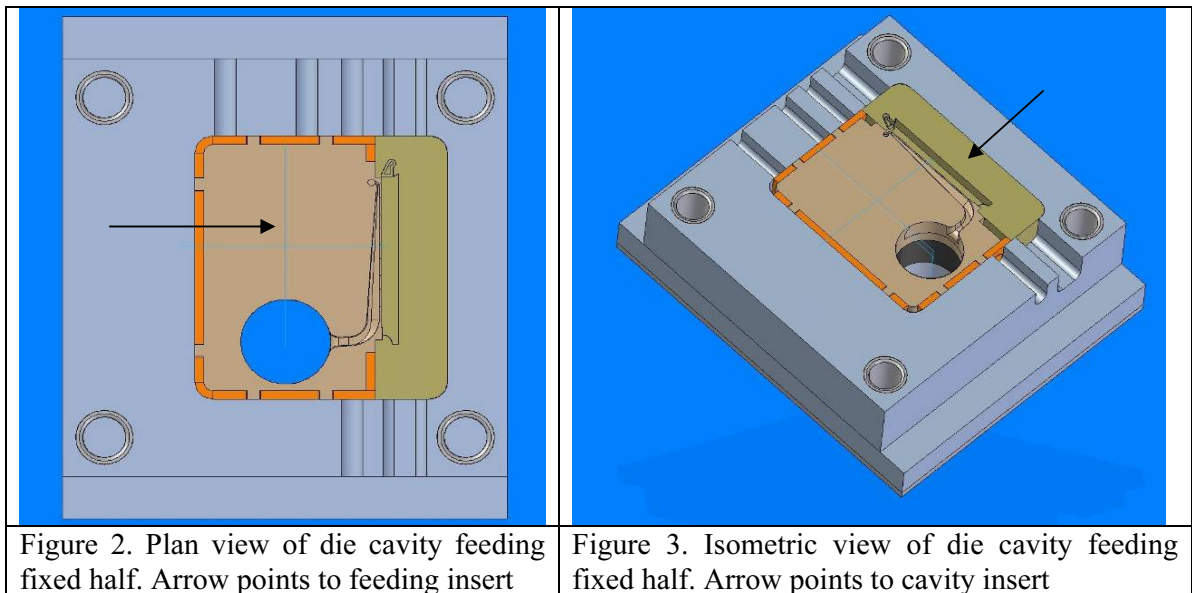


Figure 1. Industrial type component design courtesy **Murray and Associates [2]**

Die test evaluations of both standard and special high temperature die material (Anviloy 1150) were done in the test die design shown below. The experimental modular designed die consists of four machined inserts. The configuration allowed use of readily manufactured sets of the feeding system including the runner made of standard hot work steel DIN 1.2344 AISI, equivalent H13, and Anviloy 1150.



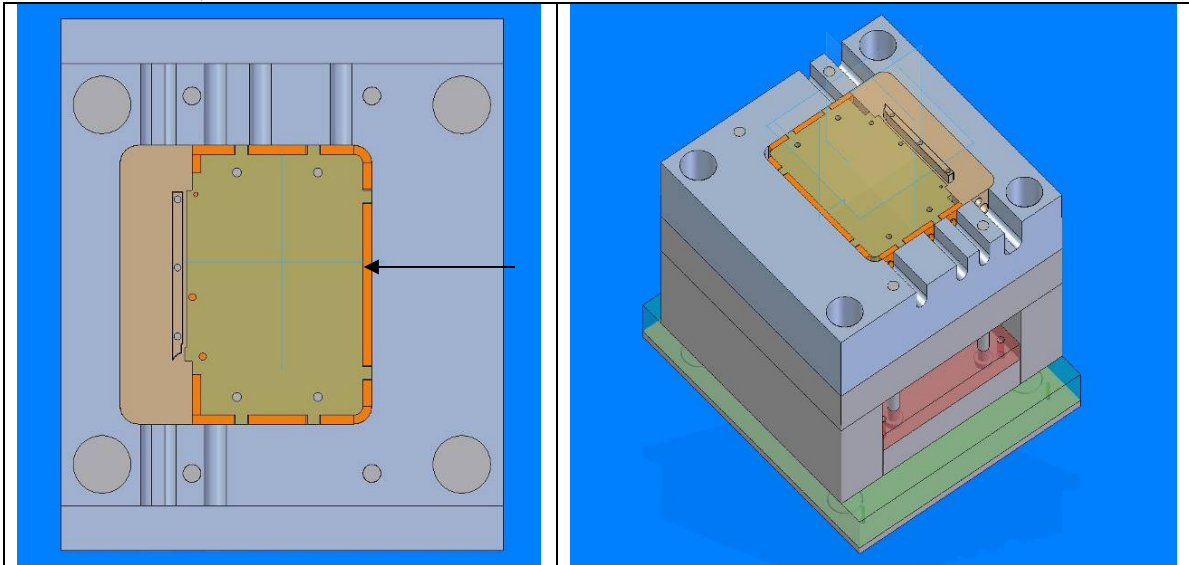


Figure 4. Plan view of die core ejecting moving half. Arrow points to insulation

Figure 5. Isometric view of die core ejecting moving half

The set of H13 inserts incorporated an optimized designed runner system following NADCA and Dr Murray & Associates [2] design rules, procedures and calculations. In the Anviloy 1150 set of inserts the gate was machined using the same geometry as for the H13 insert, only it was scaled down by 30%. This will mean a reduction of 30% in the gate and runner volume, with subsequent reduction in Aluminium used during casting.

The die design philosophy was based on standard bolsters, made from hot work steel, through hardened and tempered cavity inserts and replaceable inserts on the feeding system incorporating the runner area.

The temperature in the Anviloy 1150 inserts was controlled separately to that of the die with high service temperature heater cartridges, and was operated at a temperature of approximately 300 - 450°C. The temperature was controlled in such a way to ensure the melt solidifies before the mould opens for part ejection to take place. Separate cooling channels were drilled close to the gate area to create the possibility of rapid cooling in this area, should the need occur. The Anviloy 1150 inserts were insulated from the rest of the cavity plate to prevent heat transfer into the H13 cavity insert and the rest of the mould. Excessive heating of the H13 steel would likely result in softer material, promote wetting and could increase cycle times.

2.2 Die casting trials

A 130T Impress High Pressure Die Casting Machine was used. Die clamping and shot sleeve integration was taken into consideration in the die design. The machine is equipped with shot control.

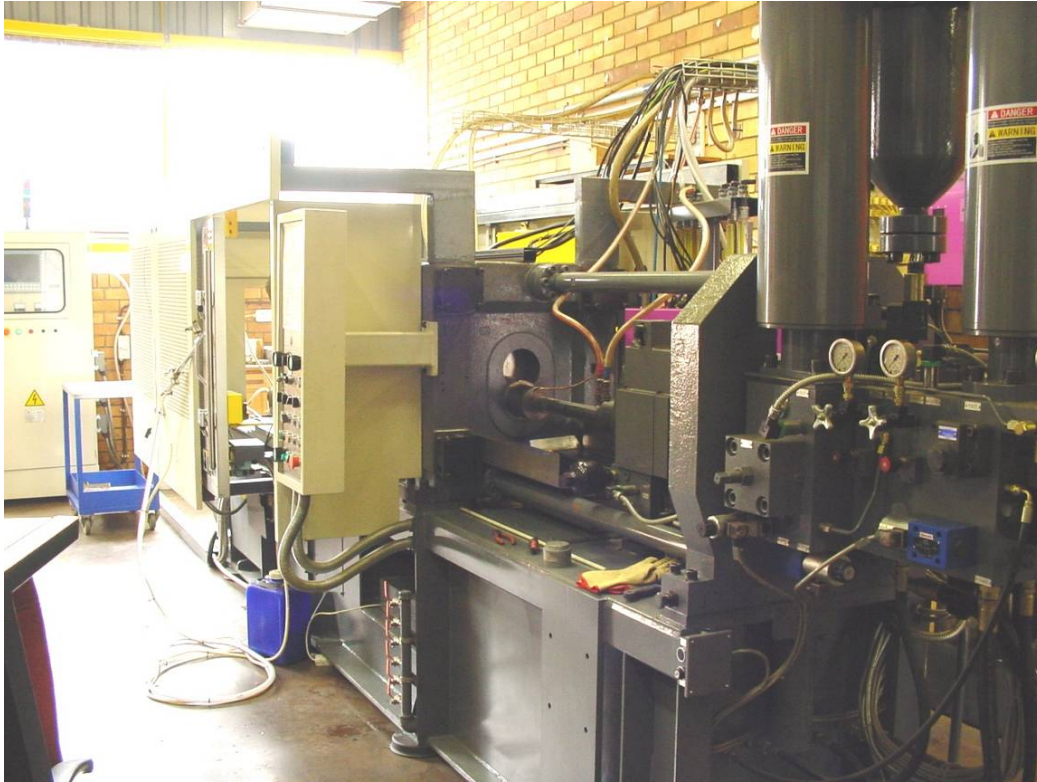


Figure 6. 130T Impress high pressure die casting machine with shot control, manufactured by LK Machines, China.

The initial trials with the conventional H13 set of feeding inserts used a plunger speed of 1m/s and final pressure of 90 Bar to fill the cavity. These initial settings were not producing good shots and were readjusted to the shot and pressure profile shown in the table below.

Plunger Tip Position (mm)			Pressure (bar)		Injection Time (sec)	Cooling Time (sec)
0 – 20	60	160	Accumulator	Intensify		
Speed (m/s)			90	80	4	8
*0.4	0.7	1	100	60	4	12
**0.1	0.2	0.4				

Table 1. Settings used to cast with H13 runner inserts. * Initial settings at 200°C, ** Final settings

The die temperature was maintained at 200°C and the Aluminium alloy 356 melt was held at about 660-690°C.

The production trials with the Anviloy 1150 set of inserts used initially similar settings to the H13 counterpart, but required some adjustment in order to be able to produce good shots. The in die experimentation plan implemented initially had Anviloy inserts incorporating a 30% smaller runner, run at 200°C. The same

processing settings were used with the H13 base runner insert. The results were not good; the cavity could not fill with the same quality as its full size H13 runner counterpart. Further experimentation showed that when the Anviloy insert temperature reached just over 300°C the cavity was filled with comparable quality using the same settings of the H13 counterpart. Further trials showed that processing speeds could be further lowered, since increased Anviloy insert temperatures close to 400°C were achieved.

The die insert temperature was raised to above 400°C, which was required to minimize the mean temperature difference (ΔT) between the aluminium melt and the surface of the inserts containing the biscuit and runner. Processing aluminium with tungsten inserts should be kept below a ΔT of 200 °C to avoid brittle and or plastic transition induced stress beyond the yield point of tungsten that might result in cracking the die inserts. The settings in Table 2 were used in these trials.

Plunger Tip Position (mm)			Pressure (bar)		Injection Time (sec)	Cooling Time (sec)
0 – 20	60	160	Accumulator	Intensify		
Speed (m/s)			100	60	4	12
*0.1	0.2	0.4				
**0.08	0.1	0.1	90	50	4	12

Table 2. Settings used to cast with Anviloy 1150 runner inserts. * Anviloy insert temperature set at 300°C. **Anviloy insert temperature set at 400°C.

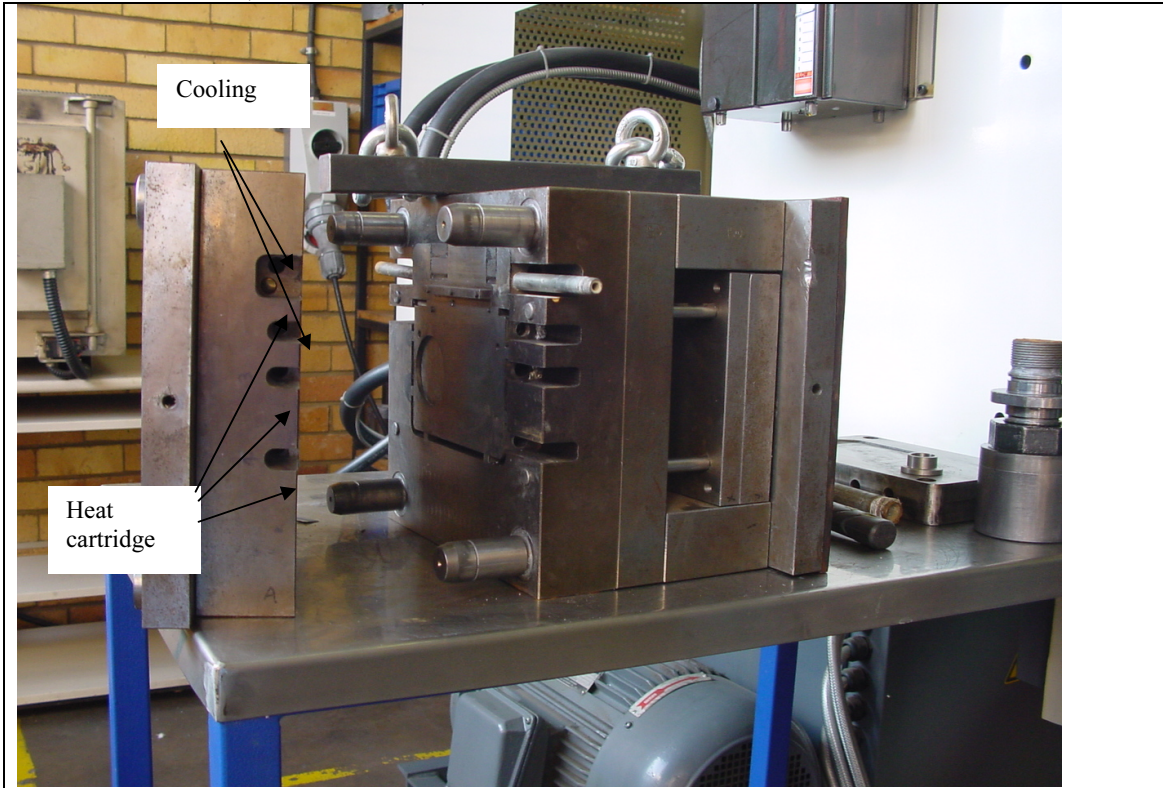


Figure 7: Experimental Die allows for 3 off diameter 12mm full wattage electrical heat cartridges complete with thermocouples in each half as well two cooling lines on the cavity and runner gate area.



Figure 8. Moving half test die



Figure 9. H13 feeding area insert after producing 5 000 shots



Figure 10. Anviloy 1150 feeding area insert After producing 5 000 shots

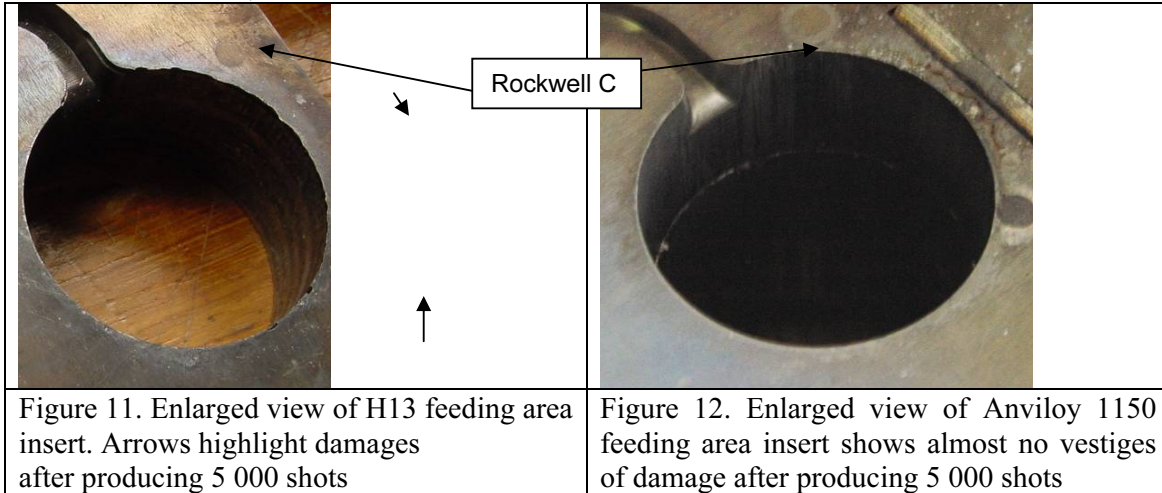


Figure 11. Enlarged view of H13 feeding area insert. Arrows highlight damages after producing 5 000 shots

Figure 12. Enlarged view of Anviloy 1150 feeding area insert shows almost no vestiges of damage after producing 5 000 shots

After running 5 000 shots with both sets of runner inserts, evidence of softening of the H13 inserts was found, while the Anviloy counterpart did not show any evidence of softening, cracking or aluminium soldering. A Rockwell C hardness testing machine was used to measure hardness. Readings were taken on both inserts on areas affected or close to where melt heat induced cyclic temperature occurs, prior to and after experimentation.

2.3 Die casting process simulation

3D simulation and optimization of the component and runner were done using ProCast software. The runner and component 3D model was initially modelled, using Solid Edge software. It incorporates a runner system designed following Murray [2] runner design principles. The optimized runner and gate geometry were scaled down by 30% and fill simulations were carried out.

A few flow simulations were done, which included 3D model runner alterations in order to obtain a component with the least porosity and distortion. Integrated simulations replicating the newly proposed process conditions as listed below were done:

- Multi-zone die temperatures: H13 cavity forming insert at 200°C and the Anviloy 1150 runner inserts at approximately 450 °C.
- Special insulating materials around the runner forming inserts to prevent heat transfer to the cavity forming inserts.

3. RESULTS AND DISCUSSION

All the data for the various models were captured and the best results were compared with the runner system according to Murray's runner design principles. This gave a clear indication of which model to use during the die design and manufacturing process. The simulation indicated that the gate sizes should not be

reduced, but rather kept the same as previously calculated. Casting trial results were very close to what the simulation indicated. Component filling stages are shown below.

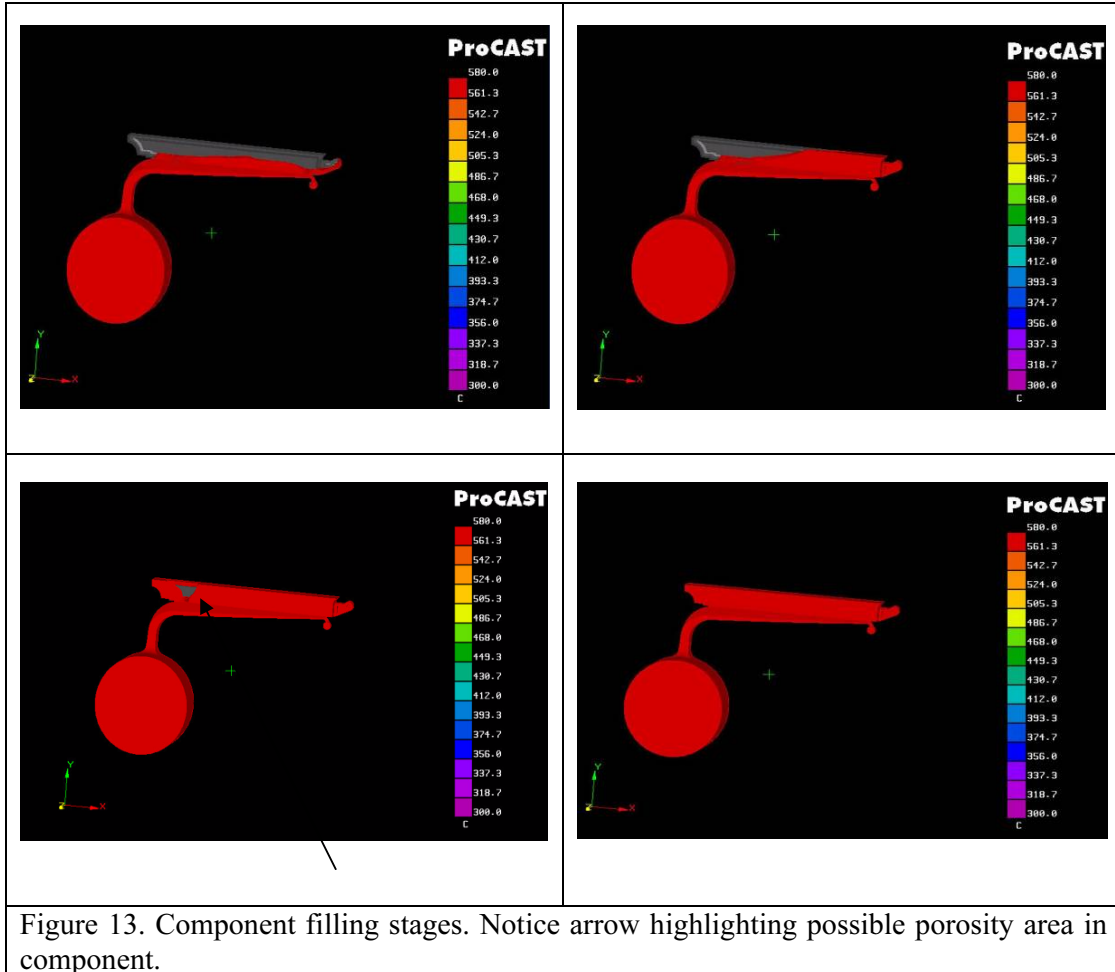
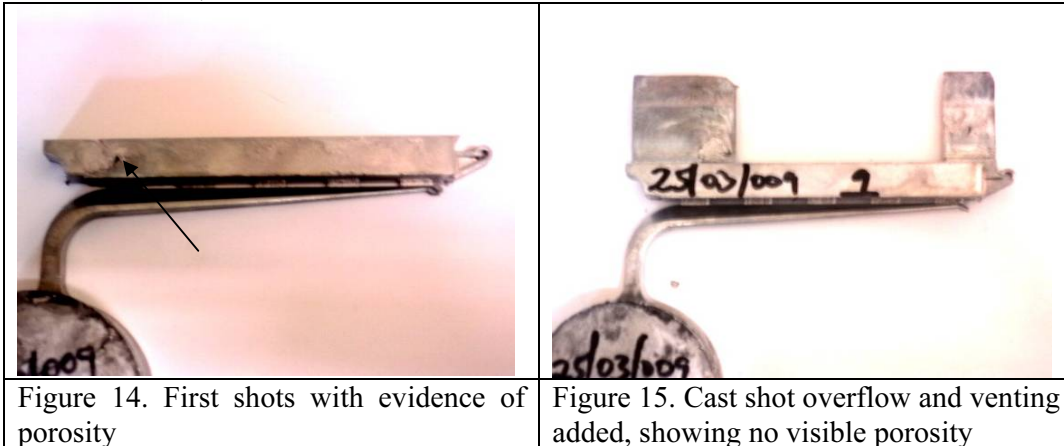


Figure 13. Component filling stages. Notice arrow highlighting possible porosity area in component.

Initial trial shots confirmed the simulation results. Adding overflows and venting solved the problem.



Quite encouraging results were obtained, clearly demonstrating the hypothesis that indeed the runner area can be significantly reduced if it is permitted to operate at temperatures closer to the melt temperature.

The differential between the aluminium melt temperatures experienced at the die surface and the temperature of the interior of the die, ΔT , is called heat shock in high pressure die casting circles. This phenomenon is primarily responsible for the associated heat checking and formation of cracks leading to premature die failure. A lower temperature differential between core and die surface clearly indicates the possibility of a much longer die life.

A number of production runs were done with the experimental die. Some were planned, others were forced due to unforeseen problems. Problems encountered were either related to the quality of components produced, such as evidence of excessive porosity, and or allied to one or other die failure, such as ejector system seizing and ejector breakage. Most of the failures were encountered when processing with the Anviloy feeding system inserts. Initially ejectors were seizing due to the different rates of expansion of the tungsten based material and the standard hot work ejectors, because standard tolerances did not apply. This failure was corrected by enlarging according to the rate of expansion of the corresponding ejector guide holes on the Anviloy inserts.

Another major problem encountered, was caused by aluminium welding to the punch. The picture below clearly highlights the problem.

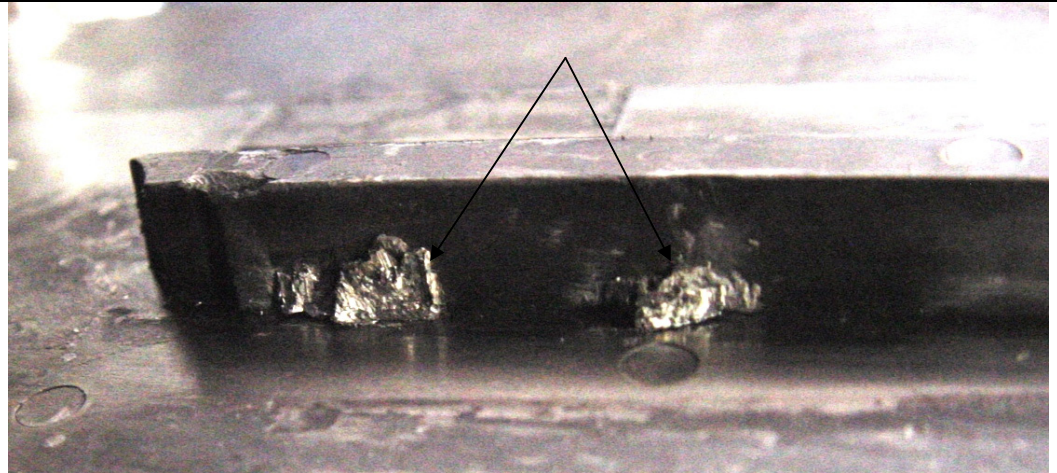


Figure 16. Aluminium welding on H13 manufactured punch

The welding phenomenon took place usually on the punch wall area opposite to the aluminium melt gate part feeding opening.

The runner gate weight ratio of 30% saving was confirmed by weighing an equivalent number of casting shots produced by the two sets of inserts. The average weight of the conventional runner was 6.34g compared with 4.24g of weight from the counterpart inserts, i.e. a saving of 2g per shot. The component weighs 12.5g and the overflows 1.45g. Overall, the saving cannot be deemed significant for this particular case, however considering that most of the components produced by high pressure die casting have a runner to part ratio of over 50% the saving potential is evident.

Microstructure evaluation of specimens cut from both runner systems was done.



Figure 17: Specimens cut from feeding tree of standard runner through the 5 gates

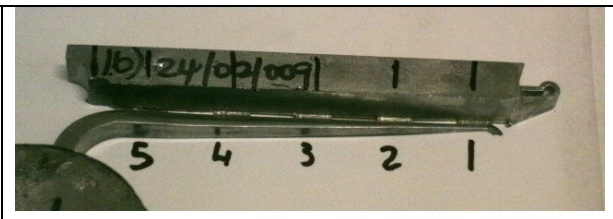


Figure 18: Specimens cut from feeding tree of 30% reduced runner through the 5 gates

The main experimental approach used to evaluate the level of porosity found in the parts fed by the two runner configurations was through microscopic evaluation of specimens taken from the areas shown in Figure 19. The worst case specimens are shown below.

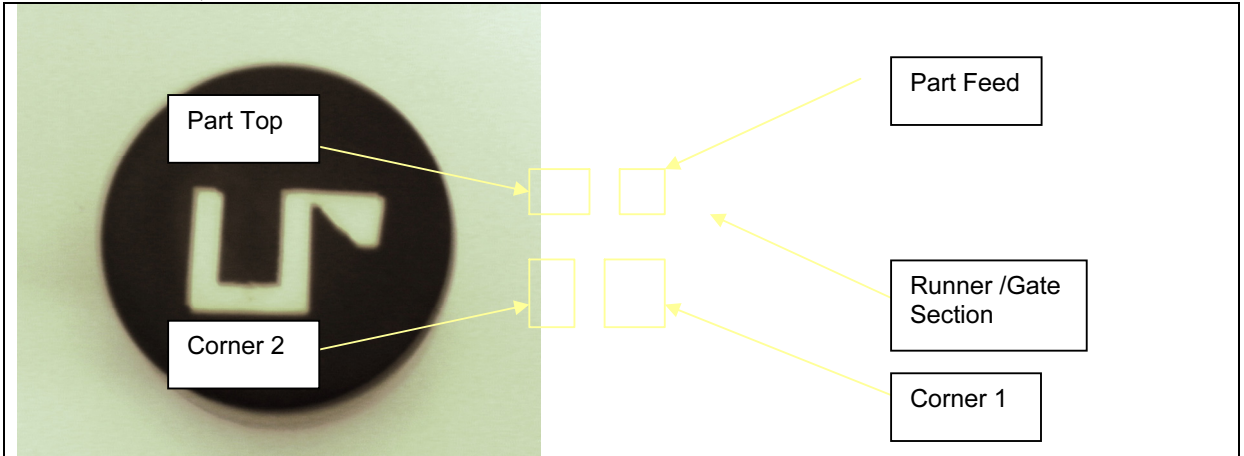
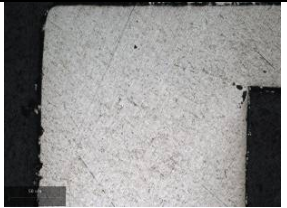


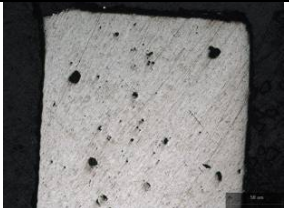
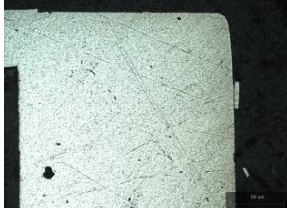


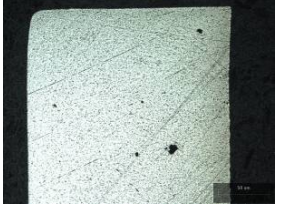





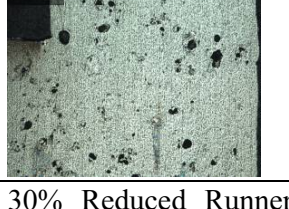
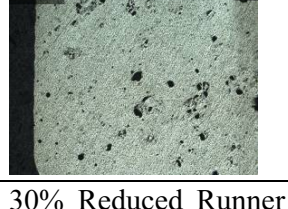
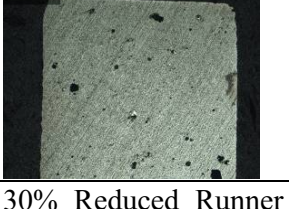
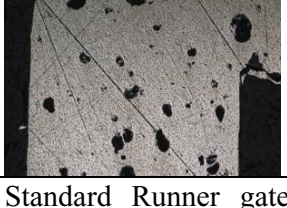



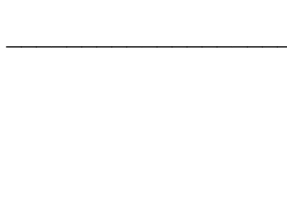
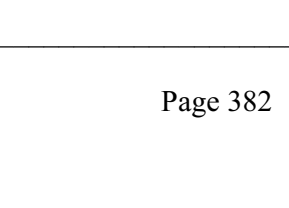
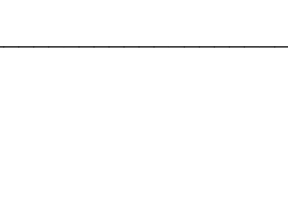

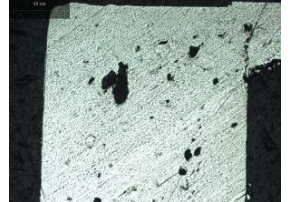
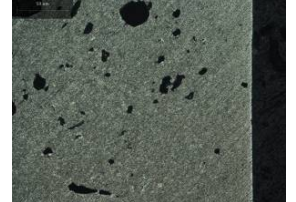
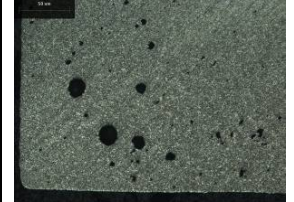
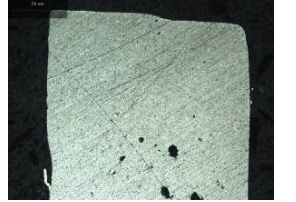


Figure 19: Typical specimen cut through one of the runner and gate section

Standard Runner gate section 1 (50x) enlarged part feed	Standard Runner gate section 1 (50x) enlarged part corner 1	Standard Runner gate section 1 (50x) enlarged part corner 2	Standard Runner gate section 1 (50x) enlarged part top
30% Reduced Runner gate section 1 (50x) enlarged part feed	30% Reduced Runner gate section 1 (50x) enlarged part corner 1	30% Reduced Runner gate section 1 (50x) enlarged part corner 2	30% Reduced Runner gate section 1 (50x) enlarged part top
Standard Runner gate section 2 (50x) enlarged part feed	Standard Runner gate section 2 (50x) enlarged part corner 1	Standard Runner gate section 2 (50x) enlarged part corner 2	Standard Runner gate section 2 (50x) enlarged part top
30% Reduced Runner gate section 2 (50x) enlarged part feed	30% Reduced Runner gate section 2 (50x) enlarged part corner 1	30% Reduced Runner gate section 2 (50x) enlarged part corner 2	30% Reduced Runner gate section 2 (50x) enlarged part top

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gate section 2 (50x) enlarged part feed	gate section 2 (50x) enlarged part corner 1	gate section 2 (50x) enlarged part corner 2	gate section 2 (50x) enlarged part top
			
Standard Runner gate section 3 (50x) enlarged part feed	Standard Runner gate section 3 (50x) enlarged part corner 1	Standard Runner gate section 3 (50x) enlarged part corner 2	Standard Runner gate section 3 (50x) enlarged part top
			
30% Reduced Runner gate section 3 (50x) enlarged part feed	30% Reduced Runner gate section 3 (50x) enlarged part corner 1	30% Reduced Runner gate section 3 (50x) enlarged part corner 2	30% Reduced Runner gate section 3 (50x) enlarged part top
			
Standard Runner gate section 4 (50x) enlarged part feed	Standard Runner gate section 4 (50x) enlarged part corner 1	Standard Runner gate section 4 (50x) enlarged part corner 2	Standard Runner gate section 4 (50x) enlarged part top
			
30% Reduced Runner gate section 4 (50x) enlarged part feed	30% Reduced Runner gate section 4 (50x) enlarged part corner 1	30% Reduced Runner gate section 4 (50x) enlarged part corner 2	30% Reduced Runner gate section 4 (50x) enlarged part top
			
Standard Runner gate section 5 (50x) enlarged part feed	Standard Runner gate section 5 (50x) enlarged part corner 1	Standard Runner gate section 5 (50x) enlarged part corner 2	Standard Runner gate section 5 (50x) enlarged part top
			

			
30% Reduced Runner gate section 5 (50x) enlarged part feed	30% Reduced Runner gate section 5 (50x) enlarged part corner 1	30% Reduced Runner gate section 5 (50x) enlarged part corner 2	30% Reduced Runner gate section 5 (50x) enlarged part top
Table 3: Micrographs of enlarged areas of runner and gate sections of the runners			

Microscopic analysis and the water displacement method were used to determine both the density of alloy A356 and the ratio between the component's weight of volume of water displaced and real weight.

The analysis revealed that the degree and amount of porosity present on components was < 0.1% of full mass density. Therefore the components produced by the two runner systems would be acceptable based on the prescribed quality acceptance criteria. In fact, the size of pores present on parts produced by the 30% reduced runner system was smaller when compared with their standard counterpart.

4. CONCLUSIONS

The trial runs produced promising results in so far as savings on non value adding material in the runner was concerned. Further research work is envisaged in order to establish that further significant savings are possible especially when an extended die life is expected. Reducing the temperature differential between the die and aluminium melt temperatures greatly reduces the extent of cyclic expansion and contraction of die materials, somewhat lowering the extent of heat shock.

A different approach to the standard die heating and cooling was used and will need further refinement and development if it is to be adopted by industry. Economic feasibility constraints or extra cost required for adoption of Anviloy in die construction indicates that the methodology should be considered for components with higher complexity, low or minimum porosity and higher specification mechanical properties.

Lower porosity on components was achieved during the trials by reducing the ram and gate speeds considerably, falling well within the laminar flow requisites of squeeze and semi solid metal (SSM) processing. Therefore, it can be concluded that adoption of this high temperature die material will go hand in hand with adoption of squeeze and or SSM processing to produce a particular cast component.

5. REFERENCES

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Principal technologist specialized in providing product tailored solutions for tool and die design developed to suit materials and mass materials production processes.

Current activities and research interests:

Provider of technical solutions in design, development and manufacture of commercial products and matters of light metals mass production R&D.

Directly involved on the inception and creation of capabilities in:

- developing of R&D projects, relevant to light metals where there is a need for tooling,
- developing, benchmarking strategies for industry sector development,
- conducting business assessment, auditing and improvement actions for individual companies or tooling industry sector related upliftment,
- engaging with international and national R&D institutions for industry wide projects,
- developing of business plans for specific industrial sector requirements.