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Aluminium Alloy Cast Shell Development for Torpedoes

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ABSTRACT

The sand-cast aluminium alloy cylindrical shells were developed for the advanced experimental torpedo applications. The components had intricate geometry, thin-walled sections, and stringent property requirements. The casting defects, such as shrinkage, porosity, incomplete filling of thin sections, cold shuts, inclusions and dimensional eccentricity, etc were found in the initial castings trials. Improvements in casting quality were achieved through modified methodology, selective chilling, risering, and by introducing ceramic-foam filters in the gating system. The heat-treated and machined components met radiographic class 1 grade C/E standards, mechanical properties to BS1490 specifications, and leakage and hydraulic pressure test requirements relevant for such applications.

Keywords: Aluminium alloy cast shells, torpedoes, advanced experimental torpedo, shells, sand casting, chilling, risering, dross defects

1. INTRODUCTION

The torpedoes are the underwater missiles launched from the submarines. During flight, these travel at high speeds at depths of up to 500 m under the sea. The torpedo structures are made up of cylindrical, conical, or spherical shells, and house the control systems, the warhead, and other related hardwares. This paper describes the development of one of the components, viz., shell (W), which houses the warhead of an advanced experimental torpedo. The component developed was a cylindrical shell type with 571 mm height, 324 mm outer diameter, and 312 mm inner diameter, weighing 16 kg. The alloy specified was aluminium alloy LM25 (composition specifications and other quality aspects and properties are given in Table 1).

2. EXPERIMENTAL SETUP

2.1 Casting & Pattern Design

The sand-casting method was chosen to develop the components. The standard aluminium alloy foundry practices[1], with suitable modifications developed in-house[2], were implemented in the initial stages. The component geometry was modified so as to avoid sharp corners, minimise the number of cores required and to have 5–7 mm machining allowance wherever required. The shrinkage allowances were determined during trials using a wooden pattern and an expanded polystyrene core box. Based on these trials, the shrinkage allowances were calculated to be ~ 0.3 per cent of the diameter and ~ 0.7 per cent of the length of the component.

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Table 1. Specifications and actual properties achieved

Component	0.2 % PS (MPa)	Hardness (VHN)	Radiographic grade	Composition			
				Si	*Mg*	*Fe*	*Al*
Shell (W)	207-232	116-128	B/C/D	6.6	0.40	0.24	Bal.
SPECS (*Al*-alloy LM25 /BS1490)	200	95	C/E	6.50-7.50	0.20-0.60	0.50 max.	Bal.

Following this, teakwood patterns and core boxes were fabricated from high quality teakwood.

2.2 Methodology

For a large casting height of Approx. 600 mm, it was felt that the conventional bottom gating may pose filling problems. Therefore, it was decided to orient the casting horizontally, with a single parting along the cylinder diameter.

The sand mould and cores were prepared using dry silica sand of – 80 + 120 mesh size with 4 Wt. per cent sodium silicate grade C (Foseco, India) as the binder. The binder was mixed with sand for 5 min before moulding. Mixed sand was hand-compacted, and CO_2 gas was passed for 10 s through a number of vents made in the sand. Hardened moulds and cores were coated using an alcohol-based graphite emulsion (Foseco Moldcote-11), and dried in an electric resistance oven at 250 °C for 4 h.

A medium frequency induction melting furnace having a 60 kg capacity crucible lined with a commercial acidic ramming mass was used for melting the alloy. The Foseco-make fluxes, salt-based degasser, and inoculant tablets were used, and the standard melting practice for aluminium alloys was followed.

Figure 1 shows one such casting with gating and risering system in place. The radiographic investigation of these castings showed the presence of gas porosity and dross inclusions. These defects were attributed to the turbulence in the liquid metal caused by the downward flow of the melt in the drag part of the mould cavity. Additionally, a casting defect known as cold shut or confluence weld (incomplete fusion between the two melt streams) occurred in the 4 mm thick wall of the internal compartment. This was related to the nature of filling of this portion under the horizontal orientation, and the melt-temperature drop in the mould cavity due to the less thickness of this portion[3]. Based on these findings, it was decided to change the orientation of the casting to vertical type. Suitable changes in the gating system were planned.

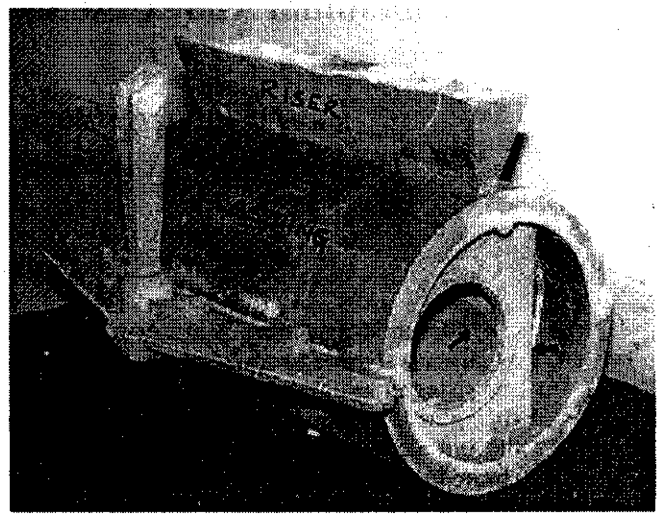

Figure 1. Horizontally poured shell (W) casting with gating and risering in place. Internal compartment is arrow marked.

2.3 Pattern & Core Box Design

A two-part cylindrical pattern was made out of seasoned BT teakwood by turning on a lathe. The core prints for the main core and the side hole core were provided on the pattern. A four-part mould was prepared using this pattern.

The core design was one of the most challenging jobs due to the internal compartment feature of the component (arrow marked in Fig. 1). Since the wall thickness of the compartment was just 4 mm (which is very difficult to cast by the conventional sand-casting), and was to be achieved without machining, mould walls had to be smooth so as to ensure proper filling during pouring. This required the mould walls facing the compartment wall to be

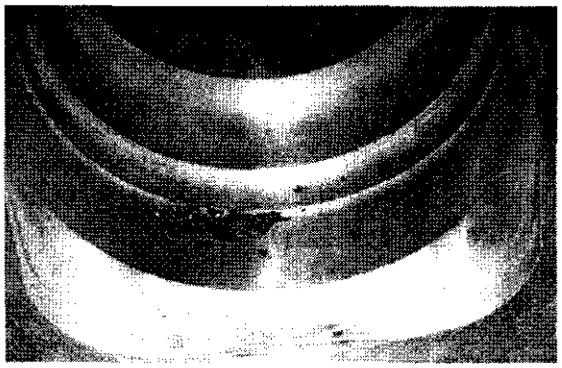

Figure 2. Shrinkage/inclusion defects (arrow marked) in the side hole as revealed during machining process.

coated by the colloidal graphite. This further necessitated the core to be made in two parts which, when assembled, would give the required mould cavity for the compartment wall. Each part of the core had to be split further in two parts for facilitating removal from the respective core boxes, making a total of four cores for the central cavity. The core boxes required to make these four cores were also made using teakwood and plywood. For side hole, a straight cylindrical core was used. The initial castings poured using this type of core showed shrinkage/dross defects in the side hole during machining (Fig. 2). These defects were attributed to the abrupt change in the casting portion thickness. In the later castings, the side core design was changed as shown in Fig. 3, which resulted in the castings free from such defects.

2.4 Core Box Assembly

Figure 4(a) shows two parts of the main core. Two sets of such cores were assembled to fabricate main core, in which a small core was inserted from the side. The total core assembly is shown in Fig. 4(b). This core assembly also shows one of the small cores used to get counter holes at the casting ends.

2.5 Gating & Risering

As mentioned earlier, the casting was made initially in horizontal orientation, and was subsequently changed to the vertical one. The gating and feeding designs for the vertical orientation of the casting have been illustrated in Fig. 5. The melt-temperature drop enters the mould cavity through the sprue, a runner, a side riser, and finally, a continuous (or slit) gate. The sprue was designed as per the

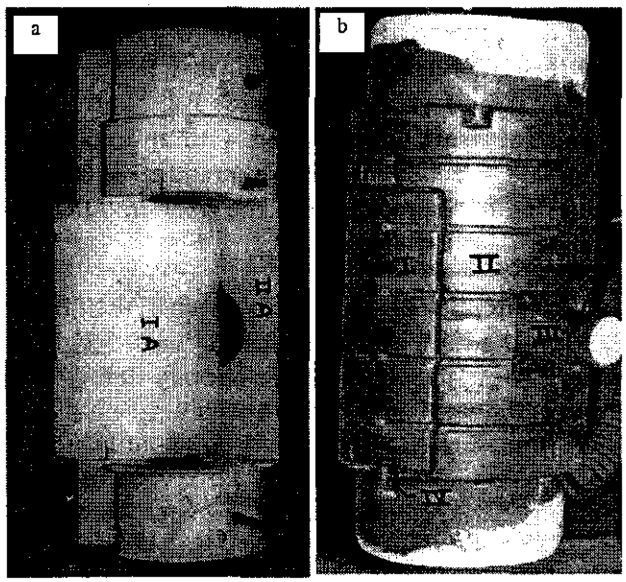

Figure 4. Gating and risering: (a) two parts of the main core and (b) main core assembly showing its four different components.

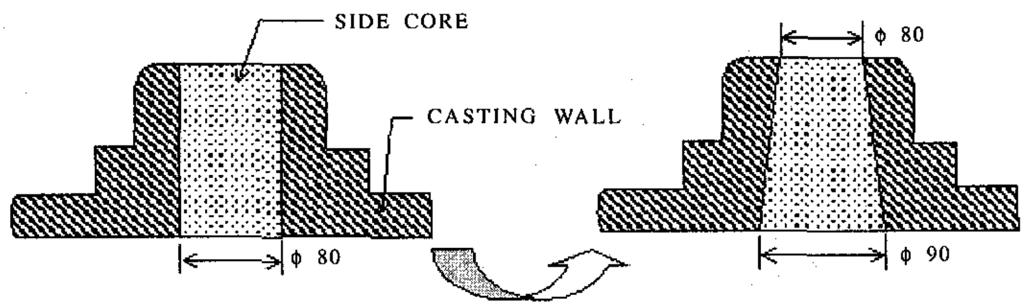

Figure 3. Showing changes in the side core design to overcome defects shown in Fig. 1.

standard practice keeping in mind the law of continuity and Bernoulli's principles to avoid turbulence[4]. A wire mesh (9 ppi) was used at the junction of down sprue and side riser. This helped in controlling turbulence and offered some filtration of dross from the melt. The side riser is known to reduce the melt turbulence[3]. The slit gate allows a relatively turbulence-free melt entry into the mould cavity and the establishment of a positive temperature gradient towards the top of the mould cavity[3]. The dimensions of various parts of the gating system are given in Fig. 5.

The casting was provided with a ring riser (feeder) on the top for feeding the solidification shrinkage. The riser also acts as a trap for floating dross particles and is removed later. Eight cylindrical risers were provided on top of the ring riser. These were insulated using a ceramic fibre paper known to delay solidification[5]. The side riser and the top cylindrical risers were topped with an exothermic compound (Feedex-4 of Foseco India) at the end of pouring to liberate heat in the riser, and thereby, improve riser efficiency.

The weight of the casting with the above-mentioned gating and riser design was 55 kg. The initial casting trials revealed a spongy defect in the top portion of the casting and near the ingate/casting junction. Increasing the ring riser height from the initial 50 mm to 100 mm, and that of the side riser from the initial 600 mm to 740 mm, eliminated these defects through better feeding of the solidification shrinkage. The changes in the riser design, however, resulted in an increase in the casting weight to 61 kg. The cooling curves were measured at various locations within the casting and the riser (Fig. 6). It can be seen that the solidification was directional towards the riser, and the riser portion remained in the liquid state until the casting locations solidified completely.

To improve the casting quality further, ceramic-foam filters (100 mm x 100 mm x 22 mm, 10 ppi size) were used in the runner for filtration of non-metallic inclusions. The dimensions of the down sprue, side riser, and the ingates were kept the same as shown in Fig. 5.

2.6 Chilling

In all the castings, microporosity was observed. This is a characteristic of the sand-casting process, and can be eliminated using chills at least in the adjacent areas due to the increased cooling rates. Separate simulation studies on 80 mm diameter

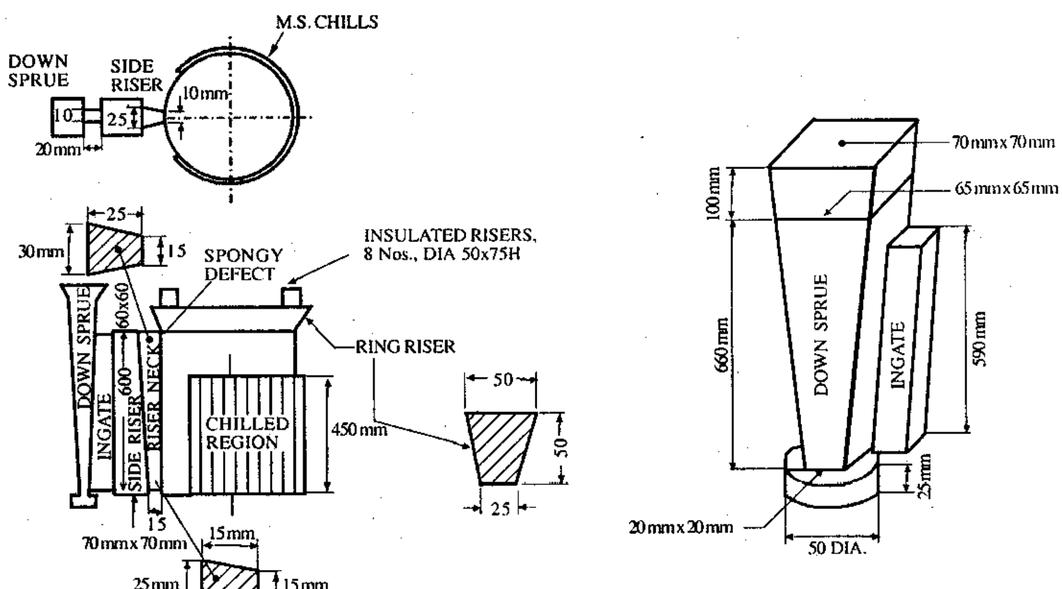

Figure 5. Gating and risering arrangement for the vertically poured casting

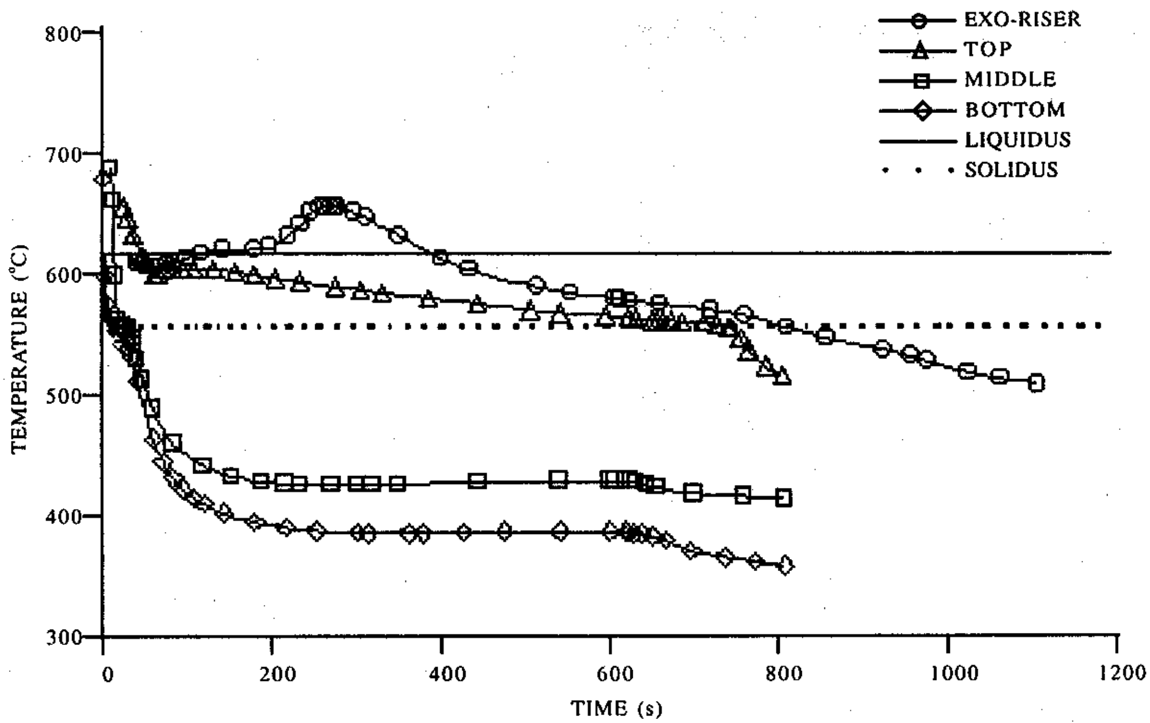

Figure 6. Cooling curves from different locations in casting and riser

sand-castings revealed that increasing the thickness of the chill up to 20 mm reduced the local solidification time, beyond which there was no appreciable change[5]. Use of 10 mm and 20 mm chills gave 25 per cent and 50 per cent reduction in the solidification time, respectively. Since the chills had to be formed to suit casting curvatures, thicker chills were not suitable. Chill thickness of 10 mm was found to be the optimum thickness from the enhanced cooling and the fabrication point of view. Chills were not used in the region near the risers so that solidification became directional towards the risers (Fig. 5). The microporosity defect was reduced substantially after using the chills. For further reductions in microporosity, rotary degassing of the melts may be necessary.

3. SOUNDNESS & PROPERTIES

The castings were subjected to 100 per cent inspection by x-ray radiography as per ASTM E-199, and the radiographs were compared with the ASTM standards. The sound castings were heat-treated as per the standard practice for LM 25 aluminium alloy[6]. The final radiography was done on the finish-machined components. A finish-machined casting is shown in Fig. 7. The weight of the finish-machined casting was 17 kg. Thus, with the optimised gating and riser design, the casting yield (component weight x 100/casting weight) was about 28 per cent. Though the casting yield achieved with the present design is somewhat low, it can be increased further by reducing the surface machining allowance. However, the casting design was a conservative one, since the quality requirements were stringent and the numbers required were low. Table 1 presents radiographic quality of castings supplied to the users. These are:

(a) Radiographic quality: The castings should be free from major defects, such as porosity, inclusions etc. The castings should be 100 per cent radiographed and should also conform to class I level C/E as per ASTM E155 standards for aluminium alloys.

(b) Mechanical properties: To meet following properties on separately cast test bars as per BS1490 (sand-cast LM-25).

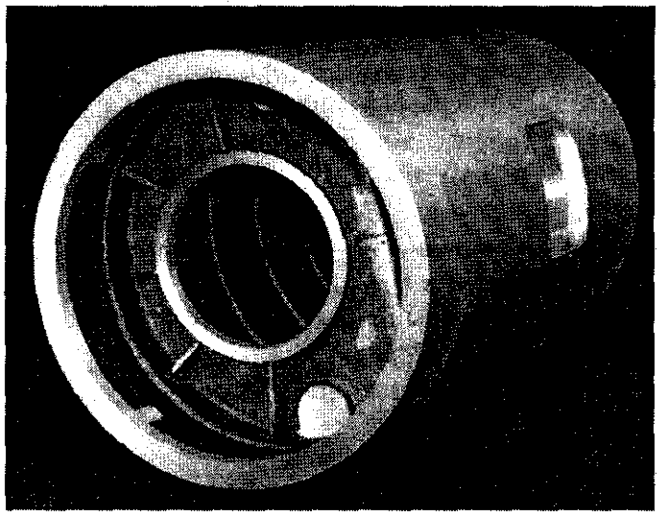

Figure 7. Finish-machined shell (W) casting

(c) Pressure tests: All the castings either individually or in assembled condition will be subjected to the following tests. These tests will be conducted on the castings in heat treated and finish-machined condition.

- Leak test: Castings immersed in water should not leak when subjected to an internal pneumatic pressure of 2 kgf/cm^2 maintained for 20 min.

- Hydraulic test: There should be no leakage or failure when castings are subjected to a hydraulic pressure of 45 kgf/cm^2 for 20 min.

(d) Dimensional tolerances: ± 0.5 mm on casting wall thickness.

(e) Supply condition: Heat-treated, machined, vacuum-impregnated and anodised (18 - 23mm thickness); helical inserts placed in drilled holes in selected locations for fitment with other components.

The dimensional inspection and fitment trials were carried out at this stage. The chemical analysis, Vickers hardness, and tensile properties were evaluated on the samples taken from the test bars (25 mm diameter, 250 mm height) separately cast in sand mould. The Vickers hardness test was carried out using 10 kg load. The round tensile specimens (gauge length 35 mm, gauge diameter 6.35 mm) were tested at a crosshead speed of 1 mm/min. Table 1 presents the results of the chemical analysis, hardness, and tensile testing conducted on the casting.

The components were subjected to leak test. The quality of O rings and their dimensions were found to be very important. The improper fitment resulting due to poor quality O rings resulted in leakages. No leakage through the casting walls was reported, when later subjected to hydraulic pressure test. The passing at the pressure test was indicative of the high quality of the cast products.

4. CONCLUSION

The aluminium alloy LM 25 cast shell (W) components were developed for the torpedo application. The sand-casting technique with suitable gating, chilling, and risering was used to manufacture the components. The heat-treated and machined components met microstructural, tensile, and leak/pressure test requirements.

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