Reasons to develop liquid hot isostatic pressing

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Abstract

Following the oil crisis in the 1970s and consumer awareness of the great harm caused to the environment by motor vehicle emissions, automakers began to overhaul their design criteria with a view to reducing fuel consumption. One of the many solutions adopted has been the extensive use of Aluminum and Magnesium instead of steel and cast iron. This has resulted in great weight savings and hence a reduction in fuel consumption. It has also given Aluminum and Magnesium foundries access to new and attractive markets. In the first substantial applications, namely the fabrication of Aluminum cylinder heads and engine blocks, quality requirements were primarily concentrated on static strength and water and oil tightness, in addition, of course, to dimensional precision. New and important uses are being found for Aluminum alloys: steering knuckles and suspension links, levers and cross members. For these families, the main quality requirements relate to fatigue and impact resistance. New alloys and new manufacturing processes are necessary to ensure that suspension components are endowed with these qualities.

The HIP – Hot Isostatic Process has been introduced several years ago has been proven one interesting and effective way of Aluminum treatment to increase fatigue strength. An evolution of the concept, known as Liquid HIP- LHIP, perfected in conjunction with Metal Casting Technology Inc., Idra Presse and Teksid is now coming on stream. It ensures quality levels and trimmed costs difficult to obtain with conventional processes.

If we take into consideration as an example the engine cylinder heads and we analyze our findings from tests carried out on more than 70 types of engines over the last 30 years [1], we can reach the conclusion that the sand-cast process is not suitable for cylinder heads on diesel engines and certain types of highly stressed petrol engines since in these applications, under heavy loading conditions, there are high risk of failure due to thermal fatigue, even when using primary alloys. This is attributable to the microstructure (dendritic arm space) and to the presence of micro shrinkage cavities between the dendrites, which are unavoidable due to the slow speed of solidification typical of this casting processes [2],[3]. Our findings also show that cylinder heads cast with the “Lost Foam” process present similar problems.

New and important uses are being found for Aluminum alloys: steering knuckles and suspension links, levers and cross members. For these families, the main quality requirements relate to fatigue and impact resistance. New alloys and new manufacturing processes are necessary to ensure...
that suspension components are endowed with these qualities [4]. These components are currently made from ductile iron, steel forging or stamping of sheets of welded steel. The new solutions made from Aluminum alloys are subdivided into two categories:

- solid shapes (e.g. steering knuckles, arms, cross members)
- hollow shapes (arms with cores) – Fig. 1

Several technologies are available for manufacturing the components of the first category like permanent mould die casting, low-pressure die casting, semisolid processing, squeeze-casting, Vacural, forging. Due to the presence of the cores, only the permanent mould die castings or the low-pressure die castings are viable solutions for manufacturing the components of the second category.

HOT ISOSTATIC PRESSING PROCESS

As it is well known from the extensive experience in production, the treatment of Hot Isostatic Pressing (HIP) [5], [6], can eliminate the micro shrinkage cavities between the dendrites and the porosity attributable to hydrogen present in the castings, defects that considerably limit the resistance to fatigue of the components.

This process has only been applied on aeronautic components due to the high costs involved attributable to the long cycle time and the burden-some safety measures required for the risk of explosion when working with compressed gases at high pressures (1000 atm) and high operating temperatures.

A new process, which we called Liquid HIP - LHIP, was devised from the works of Dixon Chandley [7] and perfected and industrialized thanks to a close collaboration between Metal Casting Technology Inc, Idra Presse, and Teksid [8].

THE LHIP (LIQUID HOT ISOSTATIC PRESSING) PROCESS

The process principle is based on the idea of applying the isostatic pressure over the casting through a liquid instead than through a gas in order to overcome the HIP cost process issues. It can be easily understood that the cycle time can be dramatically reduced (from hours to minutes) and the risk of explosion of the high pressure working vessel can be reduced to zero (the liquid pressure will immediately drop in case of leakage or failure).
The selected liquid had to fulfill the following requirements:
- low cost
- recyclable and easily washable
- non corrosive for the aluminum alloy and for the vessel material
- low temperature melting point (250-300 °C)
- high temperature boiling point (above 600°C)

A long period time has been dedicated to the testing of different solutions and a family of eutectics salts has been defined and verified. The vessel's material has been object of a deep investigation with the goal of guarantee tightness under operating conditions (Fig. 2). The selection study went through a best compromise check-loop among high temperature mechanical properties (thermal fatigue and creep at 500-600°C) and corrosion performances. A cost/performances analysis ended-up with the selection of an high strenght steel grade, able to reach the one million cycle life, instead of a infinite life nickel based super alloys.

As the HIP process, LHIP is capable of eliminating some of the typical casting defects (fig. 3) like micro and macro shrinkage porosity and hydrogen inclusion. Defects connected with the surface (i.e. cold shots, surface cracks), as well as nitrogen inclusions and oxides, cannot be eliminated: these kind of defects can be slightly modified in shape.

Process normal running parameters to obtain such results on Aluminum castings are:
- 1000-1200 ATM pressure
- 400-540°C salt temperature
- 20-35 seconds pressure applied
- 3-4 min. cycle time (charging, treating, quenching).

The LHIP effect on the microstructure of the treated castings improves the material mechanical properties and increases density (fig. 4).

In particular on sand casting, tensile and yield strength are slightly increased when compared with the untreated material, while fatigue strength can be dramatically increased up to two times. Elongation can be positively affected by LHIP, even if the casting process is the main driver in the achievable level of such an important material property. As well known oxide and DAS have a strong influence on the ductility: LHIP is not affecting those two features. Table 1 shows results achieved on A356 sand-cast specimen, with no chills, when treated LHIP, and in figure 5 the fracture surface analysis shows how micro-shrinkage porosities are eliminated after LHIP.

### Table 1
**Properties comparison**

<table>
<thead>
<tr>
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<th>Sand cast T6</th>
<th>Sand cast LHIP T6</th>
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<tbody>
<tr>
<td>Tensile strength</td>
<td>230-250 MPa</td>
<td>250-300 MPa</td>
</tr>
<tr>
<td>Yield strength</td>
<td>190-210 MPa</td>
<td>210-250 MPa</td>
</tr>
<tr>
<td>Elongation %</td>
<td>1-2</td>
<td>4-6</td>
</tr>
<tr>
<td>Fatigue Strength</td>
<td>80-100 MPa</td>
<td>120-180 MPa</td>
</tr>
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</table>
An industrial pilot plant (internal vessel diameter 470 mm and depth 1420 mm) is installed at the TEKSID Technical Centre (fig. 6-a). Running in automatic conditions the achieved cycle time is in the range of 3 – 5 minutes.

A full scale industrial plant has been defined (internal vessel diameter 900 mm and depth 2000 mm) and will be placed in between the solution and the ageing furnace. The LHIP stage will be fully integrated in the heat treatment process flow (fig. 6-b). The castings will be introduced in the salt bath, always at high temperature and water quenched before ageing. This approach can be considered the most suitable to cut treatment costs since cycle time, energy and manpower can be dramatically reduced.

Test programs are in progress: preliminary results are very encouraging both on specimen and components (fig. 7).

<table>
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<tr>
<th>Material</th>
<th>Average fatigue life (cycles)</th>
<th>Standard deviation</th>
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<tbody>
<tr>
<td>Sand casting with chill</td>
<td>72 ± 0.1</td>
<td>53 ± 15.0</td>
</tr>
<tr>
<td>Sand casting with chill</td>
<td>85 ± 7.1</td>
<td>85 ± 7.1</td>
</tr>
<tr>
<td>LHIP casting</td>
<td>85 ± 7.1</td>
<td>85 ± 7.1</td>
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</tbody>
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LHIP costs including the full T6 heat treatment are in a very competitive range given the process attractive for the automotive industry opening a bright future for this technology. As an example suspension components could be produced as sand castings or fully automated casting machines (i.e. Disamatic) and then treated LHIP with the achievable goals of high fatigue strength similar and higher than other more expensive casting techniques (i.e. low pressure casting).
The needs to reduce fuel consumption and emissions will drive the growing request of light components in the automotive industry. An increased demand will come for Aluminum safety parts. In order to get the business in this emerging market, foundries have to be ready in delivering high quality and high performances castings at competitive prices. Research and development is the key factor to be the winner in this future rush since most of the well established casting techniques cannot satisfy these demands. Breaking-through technologies will be the answer to these future needs. Based on the results achieved so far the LHIP technology can be considered one interesting alternative to produce high performances aluminium components at competitive costs both for safety components both for heavy duty engine components.

**REFERENCES**


