# Liquid hot isostatic pressing process to improve properties of thixoformed parts

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### Abstract

*Already introduced many years ago as a concept, the hot isostatic pressing process has been widely and successfully used for niche and high-performance-demanding markets such as aerospace and car racing. The main reason why this bright idea of post-processing shaped materials, mainly castings, never became an industrial process for larger markets like the automotive is cost. The means used up to now to apply high pressure on the component to be treated in a vessel at high temperature, where the material softens and compacts uniformly, is a gas.*
*This leads to long treatment time and cost issue, added to the highly risky plants where the vessel containing the parts during the treatment is working under heavy stress conditions (pressure can reach 1300 atmospheres when aluminum is treated.*
*Recently MCT-USA and Teksid-Italy developed and industrialized, in partnership with Idra-Italy a new hot isostatic pressing process, called Liquid HIP (LHIP), where the mean used to apply the pressure to the components to be treated is a liquid salt. The process can be considered a technology breakthrough. Its cost competitiveness will open a bright future in the next few years for HIP applied to aluminum automotive components for mass production, with the goal of having higher properties on treated parts and reduced scrap level in the casting process chain.*
*This paper describe the effect of LHIP on thixoformed castings.*

### Keywords

*HIP, fatigue, treatment.*

### Riassunto

Già proposto molti anni or sono come concetto, il processo di pressatura isostatica a caldo (HIP) viene ormai largamente impiegato con successo nelle forniture ai mercati di nicchia come il mercato aerospaziale e quello delle auto da corsa. L'idea alquanto geniale, di trattare sotto pressione materiali già formati, soprattutto le fusioni non è mai sfociata in un vero e proprio processo industriale di alti volumi per il costo. Il mezzo usato finora per esercitare la pressione sui componenti da trattare è un gas. Nell'autoclave ad alta temperatura e pressione, il materiale si compatta in modo uniforme.
L'impiego di un gas comporta un tempo di trattamento assai lungo e problemi di costo. Inoltre l'impianto è ad alto rischio. Il recipiente che contiene le parti durante il trattamento opera in condizioni di alta sollecitazione (la pressione può arrivare alle 1300 atmosfere durante il trattamento dell'alluminio).
MCT-USA e Teksid-Italy hanno recentemente sviluppato ed industrializzato, in collaborazione con Idra-Italy, un nuovo processo di pressatura isostatica a caldo, denominato Liquid HIP (LHIP), che si avvale di un sale liquido per esercitare la pressione sui componenti. Tale processo è da considerarsi un'importante passo avanti tecnologico. La sua competitività in termini di costo aprirà nei prossimi anni nuove prospettive all'HIP per componenti automobilistici in alluminio prodotti in grandi serie.
L'articolo illustra gli effetti dell'LHIP su getti ottenuti con tecnologia del semisolido.

### Parole chiave

HIP, fatica, trattamento.

## THE HOT ISOSTATIC PRESSING PROCESS

Aluminum alloy castings become attractive for the automotive industry when a light weight and near-net-shape component is desired to satisfy the emission legislation. Unfortunately, the presence of internal porosity in the final component can have a detrimental effect upon the mechanical properties. One technique, which has been employed to remove pores from castings, is Hot Isostatic Pressing (HIP). The HIP process involves the application of isostatic pressure to the component generally through the pressurization of an enveloping gas contained in a pressure vessel. Additionally a furnace within the vessel enables the temperature to be increased processing at high temperature is a must to decrease the flow stress of the alloy (Fig. 1) and allow the diffusion densification mechanism to become active.

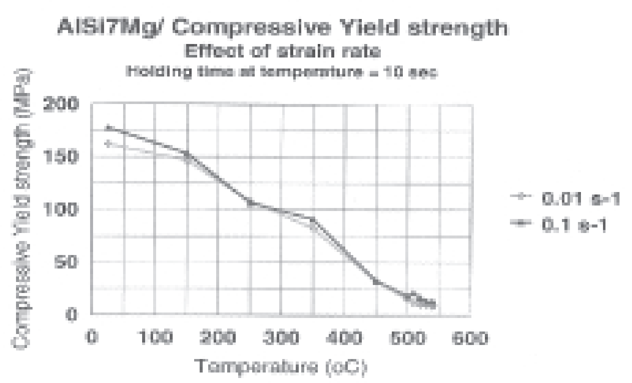


*Fig. 1: Effect of temperature on the flow stress for an aluminum alloy*

This is required to promote micro and macro pore size reduction and possibly pore elimination. While HIP has its roots in the processing of critical structural aerospace components (i.e. turbine blades), since 1970 it been applied to densify aluminum castings [1]. In particular Bodycote has recently optimized the HIP process to treat aluminum castings (Densal) [2], always using a gas as a means to apply isostatic pressure. The treated parts show no differences in microstructure when compared with the untreated parts other than the absence of internal porosity. The complete elimination of such a defect with no coarsening of the microstructure results in improved ductility and fatigue resistance. The results, shown in Fig. 2, indicate one order of magnitude or greater in the improvement in fatigue life when HIP or Densal is used as a post-casting treatment [2]. Similar results have been achieved on sand castings when HIP has been applied through a liquid (LHIP) as outlined in Fig. 3.

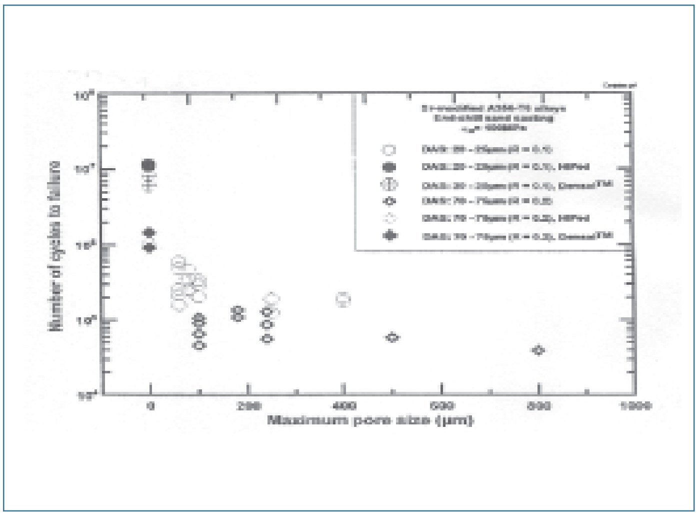


*Fig. 2: Pore size effect on fatigue properties of an aluminum alloy*

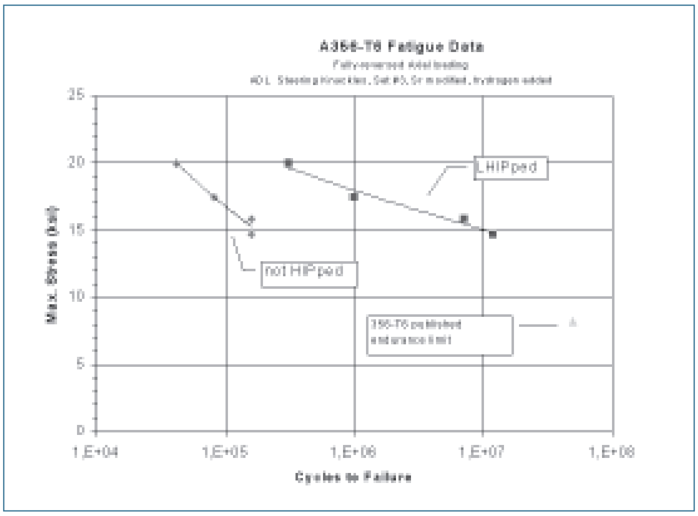


*Fig. 3: LHIP effect on fatigue properties*

## 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 of a gas 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 has to meet the following requirements:

- low cost
- recyclable and easily washable
- non corrosive for the aluminum alloys and for the vessel material
- melting point at low temperature (250-300°C)
- boiling point at high temperature (above 600°C).

After a long period dedicated to the testing of different solutions, a family of salts has been identified and technical solutions have been defined to guarantee the vessel tightness under the operating conditions as outlined in Fig. 4.

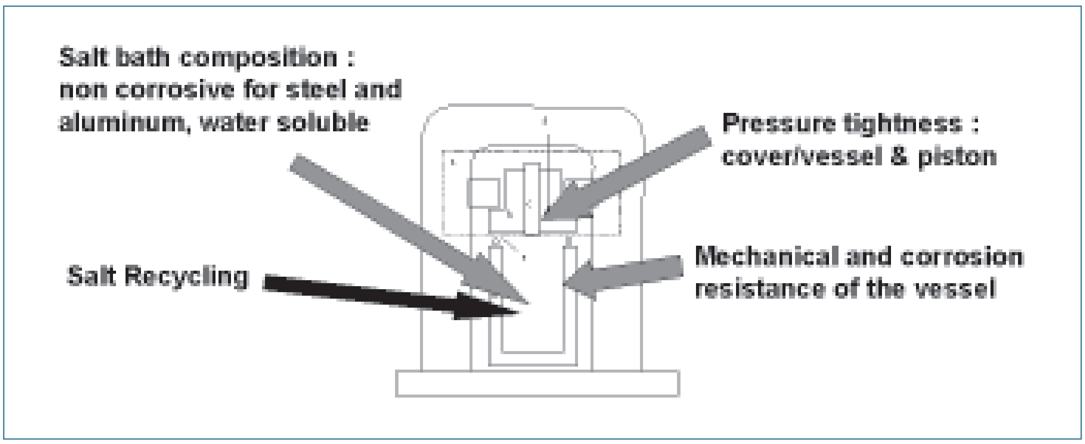


*Fig. 4: LHIP pilot plant*

Like the HIP process LHIP eliminates some of the typical casting defects (Fig. 5) 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. Process normal running parameters to obtain such results on A356 aluminum castings are:

- 1000-1200 pressure
- 500-540°C salt temperature
- 20-35 seconds pressure applied
- 3 - 4 minutes total cycle time (including heating and cooling).

The effect of such an improvement in the microstructure of the treated castings is the increase of the material mechanical properties. In particular on sand casting, tensile and yield strength are typically increased by 20% when compared with the untreated material, while fatigue strength can be dramatically increased up to three times. Also 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 ductility and LHIP does not affect those two features.

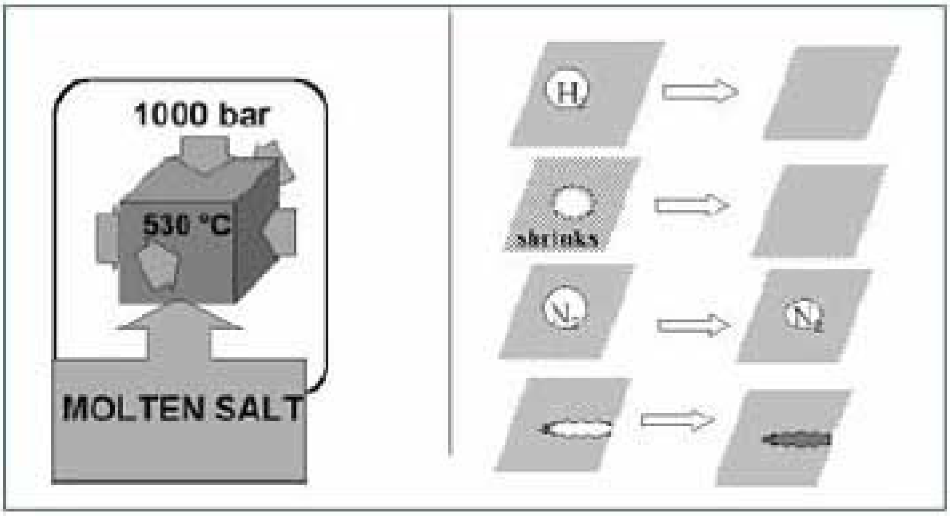


*Fig. 5: LHIP process conditions and related effect*

**TABLE 1 - Results achieved on A356 sand-cast specimen, with no chills, when treated**

| | Sand cast T6 | Sand cast - LHIP T6 |
|---|---|---|
| Tensile strength | 230-250 MPa | 300-320 MPa |
| Yield strength | 190-210 MPa | 230- 250 MPa |
| Elongation % | 1-2 | 4-6 |
| Fatigue strength | 80-100 MPa | 120- 180 MPa |

## LHIP APPLIED TO THIXOFORMED PARTS

In order to evaluate the effect of LHIP on thixoformed parts a set of suspension arms produced by Stampal Italy for TRW (Fig. 6) has been treated in the Teksid LHIP pilot plant.
The castings were scrap parts out of normal production; the goal of the first test was to have a preliminary result on the effect of LHIP on casting defects and an evaluation of achievable static mechanical properties.
Table 2 summarizes what was observed for parts quality.

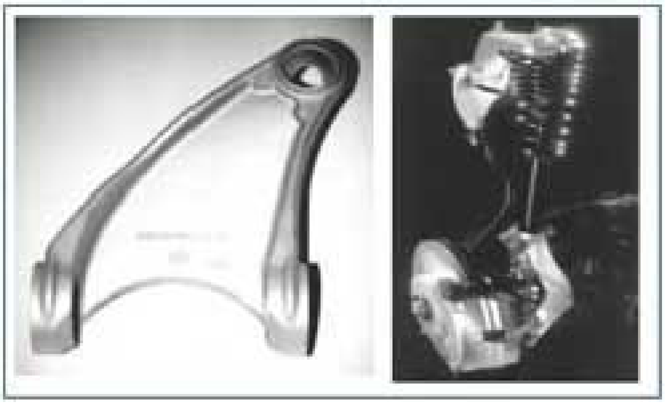

*Fig. 6: Thixoformed upper suspension arm (Stampal - Italy)*

**TABLE 2. - The effect of LHIP on thixoformed casting quality**

| Part# | As cast ZONE A | As cast ZONE B | As cast ZONE C | RX | After LHIP ZONE A | After LHIP ZONE B | After LHIP ZONE C | RX |
|---|---|---|---|---|---|---|---|---|
| N. 1 | Cold shot | ASTM 1 | ASTM 1 | Scrap | Small cold shot | --- | --- | Good |
| N. 2 | --- | ASTM 2 | ASTM 1 | Scrap | --- | --- | --- | Good |
| N. 3 | --- | ASTM 2 | ASTM 1 | Scrap | --- | --- | --- | Good |

The LHIP process is confirmed to improve all shrinkage porosity not connected with the surface without affecting the microstructure of the alloy.
The effect on mechanical properties is shown in Table 3, where the only affected value on the static properties is elongation, with a gain of 15% over the as cast material. Zones B and C refes to the direction of dissection of castings, mainly longitudinal or transversal, they demonstrate no influence of the direction.

**TABLE 3 - Effect of LHIP on properties of thixoformed castings**

| | | As cast Properties [MPa] | | | After LHIP Properties [MPa] | | |
|---|---|---|---|---|---|---|---|
| | Zone | Yield | Tensile | E% | Yield | Tensile | E% |
| | B | 267 | 304 | 6.7 | 220 | 306 | 11.4 |
| | C | 236 | 311 | 10 | 233 | 301 | 9.4 |
| | B | 235 | 288 | 4.7 | 236 | 296 | 5.7 |
| | C | 230 | 291 | 8 | 232 | 290 | 5.1 |
| | B | 254 | 310 | 6.7 | 220 | 290 | 6.0 |
| | C | 232 | 271 | 4.7 | 217 | 285 | 9.7 |
| **AVERAGE** | | **242** | **296** | **6.8** | **226** | **294** | **7.8** |

Following the above preliminary tests, series of thixoformed parts were tested in different heat treatment conditions. Each batch was composed at least 15 parts and here again two tensile specimens were obtained by dissections of castings. The average mechanical properties are in table 4, the values of the properties of samples clearly showing defects on the fracture surface were not counted for the average calculations. In order to make a comparison the values were compared with the archive data for the parts after T6 treatment. The first batch subjected to LHIP was T6 treated and then another time with the same process parameters. Two other bathces were taken in the as cast state, heated at 520 °C for 2 and 4 hours respectively, subjected to LHIP and then aged 3 hours at 160 °C.
The influence on the strength is not well defined, even though it seems slightly lower for the samples not treated with usual T6 cycle, however a great influence on the elongation properties is evident, with an increase close to about 40 % of the last series of samples in table 4 when compared with the not LHIP treated ones. Fatigue properties are under evaluation at the moment.

**TABLE 4 - Mechanical properties of parts after different heat treatment conditions.**

| Condition | Yield [MPa] | Rm [MPa] | E [%] |
|---|---|---|---|
| T6 | 224.3 | 295.1 | 9.4 |
| T6 + LHIP + T6 | 226.0 | 295.5 | 10.4 |
| 520 °C, 2 h + LHIP + ageing. | 196.1 | 273.3 | 12.5 |
| 520 °C, 4 h + LHIP + ageing. | 217.6 | 287.6 | 13.1 |

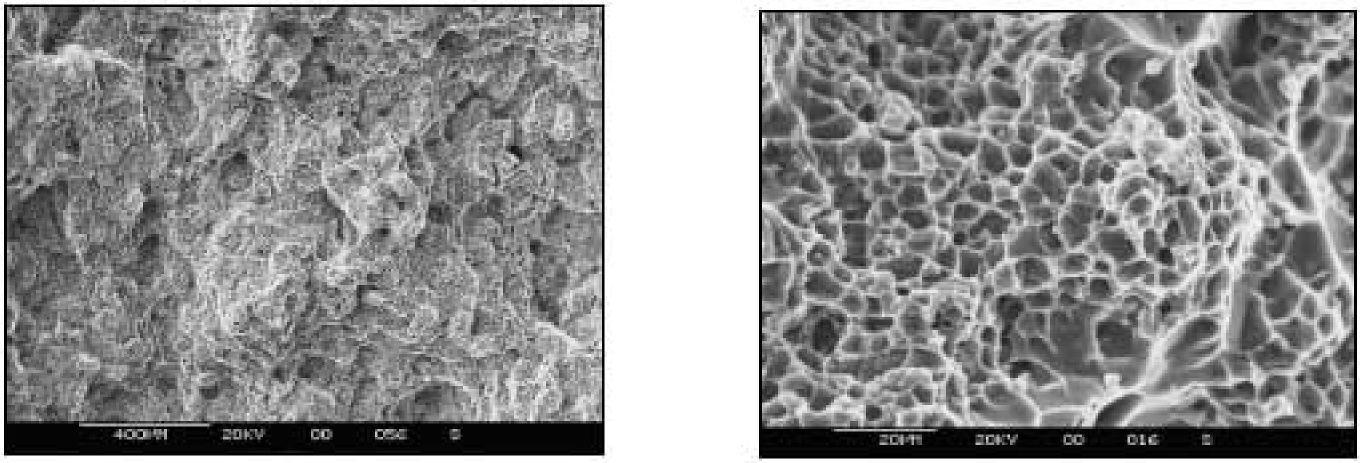

*Fig. 7: Fracture morphology of specimens after treatments: 4h at 520 °C + LHIP + ageing*

The observation of the fracture surface by SEM shows for the samples without defects mainly a dimple morphology, indicating the toughness characteristics induced by the performed processes, figure 7.

## CONCLUSION

Liquid hot isostatic pressing is a new post treatment process for aluminum casting that can improve the soundness of the parts and increase the material mechanical properties at competitive costs. When applied to sand casting or permanent mold gravity casting both static and dynamic properties are positively affected by LHIP. In this paper, preliminary results obtained on thixoformed castings show the following:

- the quality of treated parts (shrinkage porosity) is improved without affecting the microstructure
- static properties are not increased by LHIP except elongation where a 15 % to about 40% increase has been measured
- fatigue properties are expected to improve by two to three times: tests still have to be completed.

## REFERENCES

[1] G.E.Wasiliewski,N.R. Lindblad, “Elimination of casting defects using HIP” Proceedings of the 2nd International Conference, MCIC - Sept.1972

[2] Hot Isostatic Pressing of A356- SAE Paper 2000-01-0062