Liquid Hot Isostatic Processing Applied to AtSi5Cu1 Aluminum Alloy

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Abstract
The paper presents some experimental data about the liquid hot isostatic processing (L.H.I.P.) process applied to ATSi5Cu1 aluminum alloy, most utilized in the Romanian machines building industry. L.H.I.P. treatment reduced the pores mean size by about 1/3, the volume fraction by one order of magnitude and the shrinkage voids in number and volume. All experimental data, were obtained in the specific testing laboratory from Transilvania University of Brasov.

Keywords
liquid isostatic pressing, rheoforming, semi-solid forming

1. Introduction

Processing of metallic materials in heat can be done starting from the liquid state phase (all casting procedures) or form the solid state phase (all procedures of plastic deformation). With each of these procedures we can obtain pieces from metallic materials which include technological elements from both techniques - casting and forging respectively [1, 4, 5].

In the late 1980s, a joint venture process was developed between companies Hitchiner Mfg. Co., Inc. and General Motors - a new low cost casting process for titanium alloys [1, 3].

All titanium castings required Hot Isostatic Pressing (HIP) to achieve good mechanical properties. The conventional HIP process, which uses argon gas to apply high pressure for closing internal porosity, is very effective, but very dangerous and costly - too much so for the commercial applications. Most of the time involved in gas HIP cycle was, and is, involved in heating up the charge and raising the pressure of the argon gas, resulting in very long, 16-24 hour, machine cycle times.

Since it takes so long to get the gas HIP units up to temperature and pressure (and to cool them down), there was little information about exactly how long it actually takes to close porosity in castings at a given pressure and temperature. It was surmised that, if the actual time, with reference to LHIP process, the required parameters – respectively temperature and pressure were maintained on the order of 15 to 30 seconds – so an important time of reducing cycle gives finally a very important economy of time and money.

2. The L.H.I.P. Process

The process principle is based on the idea of applying the isostatic pressure over the castings 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 eliminated as the liquid pressure will immediately drop in case of leakage or failure.

The selected liquid must fulfil the following requirements:

- low cost;
- recyclable and easily washable;
- non-corrosive for the duralumin alloy and for the vessel material;
- low temperature melting point (250 – 300) °C;
- high temperature boiling point (above 600 °C).

Much time has been dedicated to the testing of different solutions and a family of eutectics salts have been defined and verified.

The vessel's materials has been subject to a deep investigation with the goal of guarantee tightness under extremely operating conditions.

As with the HIP process, LHIP is capable of eliminating some of the typical casting defects such as 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 although these kind of defects can be slightly modified in the shape.

The LHIP effect on the microstructure of the treated castings improves the material mechanical properties and increases density. In particular on sand casting, tensile and yield strength are slightly increased when compared with the untreated material, while fatigue strength can be dramatically doubled. 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.

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 [1, 2].

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, oxides have a strong influence on ductility and LHIP does not affect those two features.

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.

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).

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 [1, 7].

Process normal running parameters to obtain such results on aluminum castings are:

- (100-120) MPa pressure;
- (500-540) °C salt temperature;
- (120-135) seconds time of applied pressure;
- (5–6) minutes total cycle time (including heating and cooling).

Liquid hot isostatic pressing is a new post treatment process for aluminum castings 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 [6].

3. Experimental results

All experimental procedures were applied to thixoformed aluminum alloy with globular structure after stirring process.

The technology goes mainly through the following stages:

- heating the metallic alloy in the field of liquid or partially liquid phase;
- vigorously stirring the alloy until it reaches the temperature where the value of the primary solid is (50 ÷ 65)%;
- isothermal maintaining the alloy at the above temperature and continuing stirring;
- the obtained composition can be casted in the semisolid state or isothermally maintained for further use, like plastic deformation or casting.

To highlight better the results obtained after deformation in slurry state of the aluminum alloys, there was made a research program in which were gathered samples trough more methods of processing in heat of the aluminum alloys, starting each time from the molten alloy and these are:

- samples obtained through free casting in metallic mould;
- samples obtained through free casting and stirring in a slurry state in metallic mould;
- samples obtained through plastic deformation in slurry state in metallic mould after stirring;
- samples compressed as LHIP.

There were used for experiments all types of measuring tests and the same laboratory equipments, like:

- electric furnace, used for melting of aluminum alloys;
- mould and plunger die, made from 40Cr10 steel, used for making the samples;
- crucible for melting of alloy, made from cast iron painted inside with refractory paint based on graphite, in more layers.
- for making the semisolid slurry, there was used a mixer with a rotating speed of 180 rpm;
- HIP equipment;
- 200 kN hydraulic press;
- universal testing machine.

In the research programme were made several standard test samples, which were tested according to SR EN 1002-1 and samples for making metallographic analysis for structure of the processed alloy [7, 8].

From the many procedures for obtaining the semisolid slurry, were chosen the mechanical mixture in the overheated mould until it reached the temperature of the liquid alloy.

For each sample set, were made minimum ten determinations and then, was calculated their arithmetic average.

Each sample set was made from aluminum alloy ATSi5Cu1 – very used in Romanian automotive industry [7, 9].

After all these techniques, all the samples were maintained in molten salt at 510 °C and 100 MPa for 130 seconds and respectively it was applied the LHIP process [7].

Some experimental results are given in Table 1 and Table 2.

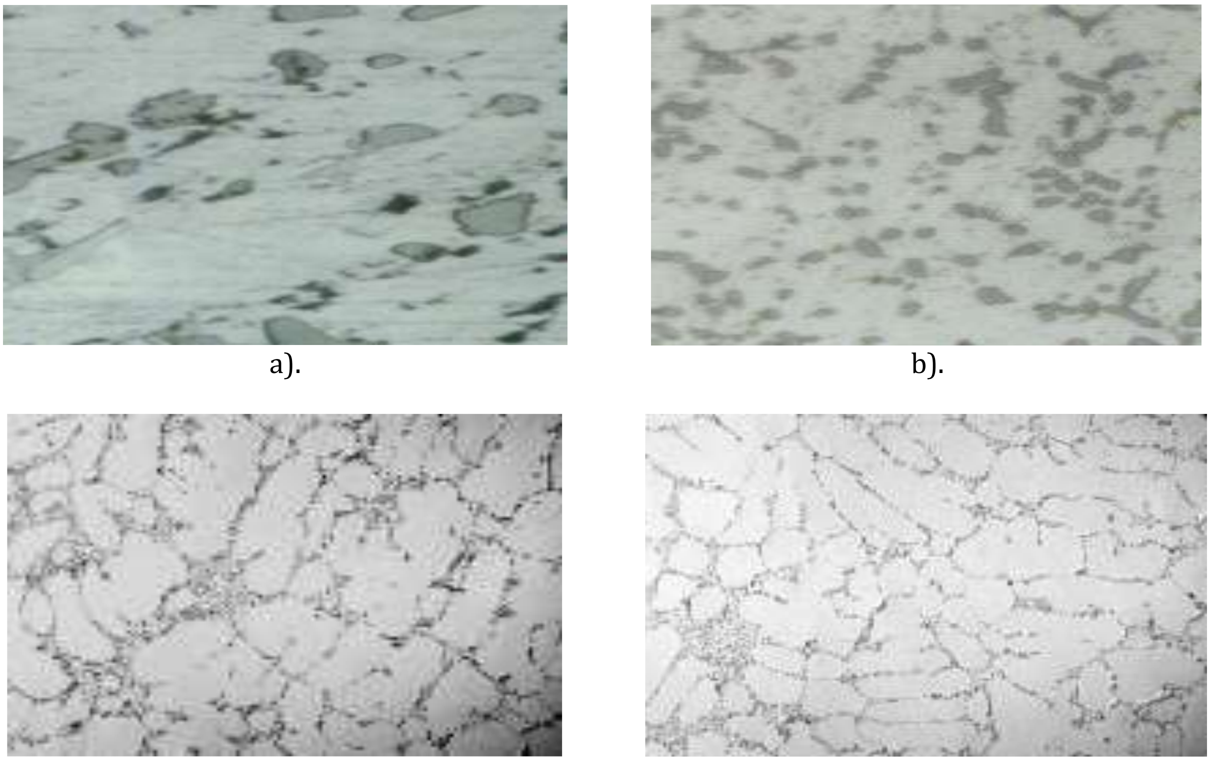
Table 1. Experimental data with elongation results for ATSi5Cu1 alloy

Elongation (δ) / The procedure for obtaining the samples	Sample set No. 1 [%]	Sample set No. 2 [%]	Sample set No. 3 [%]
a). Free classic casting	2.43	2.71	2.78
b). Casting from semisolid state	0.87	0,82	0.85
c). Plastic deformation after casting from semisolid state	3.75	3.62	4.02
d). LHIP process after plastic deformation	7.21	7.32	7.45

Table 2. Experimental data with tensile strength results for ATSi5Cu1 alloy

Tensile strength (σ_r) / The procedure for obtaining the samples	Sample set No.1 [MPa]	Sample set No.2 [MPa]	Sample set No.3 [MPa]
a). Free classic casting	139.2	127.8	135.4
b). Casting from semisolid state	107.2	110.6	118.1
c). Plastic deformation after casting from semisolid state	175.2	172.4	175.4
d). LHIP process after plastic deformation	192.3	195.2	197.2

The metallographic structure for samples, made for the four different procedures for ATSi5Cu1 alloy, are presented in figure 1.



a). b).

c). d).

Fig. 1. Metallographic structure for samples, made for the four different procedures for ATSi5Cu1 alloy (x 250)

4. Conclusions

After analyzing the above data, we can conclude that the globular structure obtained by deformation in semisolid state, leads to obtain some mechanical characteristics better than other procedures taken into consideration.

From a closer examination of figure 1, it can be observed that between the structures taken for study, there are a series of differences, and these are:

- firstly, the plastic deformed samples in semisolid state don't have micro porosities;
- the degree of scattering of the CuAl2 type of compounds, is more outlined in the case of samples made through deformation on semisolid state;
- the homogeneously of the structure of samples deformed in semisolid state is bigger than in the case of samples made through other procedures taken into consideration.

The values of the extent at breaking in the case of deformation after LHIP, are in average of 38.22% higher than the values obtained in the case of samples made by free casting and of 52.54% higher than in the case of samples made through deformation in the semisolid state.

The tensile strength resistance for alloy ATSi5Cu1 of the deformed samples after LHIP is higher, in average of 62.68 MPa than the values obtained in the case of samples made by free casting and with average of 22.88 MPa higher than in the case of samples made through deformation in semisolid state.

Although the obtained structure is spherical in all cases. The better mechanical and technological characteristics obtained in the case of samples made through plastic deformation after casting from semisolid state, can be explained by the high compact characteristics of the samples, obtained after pressing, so we can conclude that the technological process of deformation in semisolid state of the metallic materials, has a series of advantages, unlike the conventional procedures of processing in heat, for the aluminium alloys.

LHIP technology can be considered one interesting alternative to produce high performances for aluminium components at competitive costs - both for safety components and for heavy duty engine components.

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