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POROSITY IN CYLINDER HEAD CASTING OF ALUMINIUM[1]

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Abstract

The porosity in cast aluminum automotive components can compromise the quality of the casting during assembly of the internal combustion engine. The concentration of the porosity in large quantities can cause problems communicability between walls melt causing leaks like for example mixing oil and water the mechanical component in service. Porosities very near the surface of the machined head engine, below the joint seal, can cause leakage in the coupling cast components. The casting must provide a component with high internal health, free of voids and / or cavities in the melt, but the mechanism of formation porosity is associated with problems inherent in the process of the gravity casting alloys. The Presence of iron oxides and intermetallic phases, no cleaning bath and a favorable environment for the incorporation of gas in the liquid metal to be considered to the formation of porosity in the molten aluminum metal during solidification. In this paper, reported to clean the alloy liquid with salt pans in preheated during the degassing with nitrogen gas (N_2), since this salt is used to keep the liquid bath protected from contact with moisture in the air, the main source of hydrogen gas (H_2).The cylinder head motor aluminum was chosen for the study because it has thin walls with internal cavities narrow and is powered by a homogeneous volume of liquid material (feeder) which in this case has a regular geometric shape and mass. Every section of the cylinder head just below the feeder was the area selected for analysis because of this proximity to the hot melt supply and therefore prone to the appearance of porosity. The results of the experiment to reduce the porosity due to hydrogen gas using cleaning liquid alloy with salt protective preheated were significant. Since no limitation of the gravity casting process to obtain a mechanical component blown free of porosity is suggested that the functionality of this component in service will be better evaluated in the initial phase of definition of the design data for execution of the melt. Still, whichever choice of merging this component of the engine by gravity casting process, eligibility criteria should be established during the development stage of the project for the manufacture of automotive components.

Key words: Porosity; Cylinder head; Clean alloy; Casting; Aluminum alloy; Flux salt; Degassing.

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1 INTRODUCTION

Considering the high rejection rate of aluminum castings for porosity after machining by the customer decided to study the porosity and its derivatives, to better understand its mechanism of formation and mainly try to find what are the most effective means to prevent its occurrence. To do so, researched in the literature published method and / or processing technique that can minimize the formation of porosity due to hydrogen in parts during the preparation steps for obtaining liquid alloy of the casting.

2 STATE OF THE ART

There is much that the porosity has been studied by foundry men, given its presence in the metal processing and the possible consequences on the properties of the melt. The rejection rate for casting porosity increases proportionally with the increase in inclusion cast, then control is required to clean sharp metal to prevent this rejection. The use of the rotor is an effective means for degassing treating it allows the production of free parts of gas, as was observed in both experiments by Tian et al.,(1) Laslaz et al.(2) and Sigworth et al.(3) The amount of porosity is controlled primarily by the concentration of H_2, i.e. the formation of porosity can be eliminated if the concentration of H_2 in the metal is about 0.05 c.c./100 grams to 0.08 c.c./100 grams, and the test was reduced pressure able to predict the formation of porosity due to H_2 by its concentration. The reduction of H_2 can be efficiently obtained by degassing a liquid pool of melting and casting, as in their experiments consisted suggest by Campbell,(4) Campbell et al.(5) Kim et al. (6) and Zou et al.(7)

3 REVIEW FOUNDRY

Casting is a process that allows to obtain parts of complex shapes, or is a metal forming process which allows greater freedom of shapes. The casting process for manufacturing parts consists essentially of liquid metal to fill a mold cavity whose dimensions and shapes corresponding to the part to be obtained as publication John Campbell.(8) After solidification and cooling parts are obtained with final shape and dimensions under conditions of use. The castings must have characteristics of use, i.e., must have a quality standard specified by the customer, such as physicochemical characteristics of the material, mechanical properties and dimensional part.

3.1 Casting Defects

It's defined as being defective(8) when a part does not meet the contract to supply them. To verify the quality of the parts, controls are carried out or not can be destructive. Among the different types of control can be cited: visual inspection, dimensional inspection, inspection, metallurgical (chemical and metallographic analysis) and other (test mechanical properties, hardness, x-ray test, tightness, etc.).The defects result from the combination of a set of factors that sometimes make it difficult to determine its root cause. The defects may be classified:(8)

- as their appearance (macroscopic appearance) in: metal excrescences (protrusions), cavities discontinuities metal surface defects, replacement

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incomplete or incorrect forms dimensions (measured deviations), inclusions of structure (defect of material);

- as the causes of the techniques that give rise to (facilitating the study of the cause once identified) in: defects due to the mold, defects due to system design and feeder cannels, defects in order metallurgy;
- responsibility according to the personnel involved casting, and particularly, defects due to poorly executed model, molding defects due to poorly executed due to incorrect preparation of the metal.

3.1.1 Porosity

Porosity is a defect present in castings, may be characterized as a cavity within the material. The porosity can be classified as: porosity due to gas porosity due to shrinkage and porosity due to flow, with all the inherent problems associated with the process of obtaining part.[4] In the present study focused only to porosity due to gas, since during the investigation for the characterization of defects in machined parts, this type of porosity was the one with the highest rate of rejection after machining. The porosity in the casting of automotive components is a major quality problem in the casting, since it can cause leakage problems (communicability between the walls of the casting), surface defects and machining problems. Depending on its functionality, each type of part has its own tolerance limit. The level of porosity in an acceptable casting may vary considerably depending on the application part, the quantity and pores size thereof. The cylinder head, for example, have a critical need in such areas as the face of the combustion chamber, and parts which did not require mechanical stresses, may have a more demanding attenuated. The foundry men know that the porosity should be avoided because it significantly reduces the mechanical properties (especially fatigue strength and ductility) and can lead to leakage in the finished surface when the parts are assembled. The castings need to better control the gas causes the porosity, [2] which in turn depends on several parameters. The best combination of these parameters is an ongoing study of engineering manufacturing of a smelter in order to minimize the gas content in castings. In view of the limitations imposed by its own production process by gravity casting, the question absence of porosities in part should be replaced by its functionality required, considering a minimum of parts integrity.

3.1.2 The hydrogen gas (H_2)

It is known that the dissolution of hydrogen in the melt is the main factor in the formation of pores during the solidification, [1-3] since the solubility limit of hydrogen (Figure 1) in the aluminum alloy is considerably larger than other gases and is extremely low in solid alloy. Therefore the porosity in aluminum alloys has hydrogen as the main agent.[4,8] The main parameters which favor the formation of porosity are:

- chemical composition of the alloy;
- rate of solidification of the alloy;
- pressure during solidification;
- temperature gradient;
- clean the metal[1,2] (oxides or inclusions contained in the metal) which is considered as a factor that influences the nucleation of hydrogen.

Among these parameters mentioned, the cleaning liquid metal is a major factor that influences including the size of the porosity. The most important impurities in the aluminum alloys are hydrogen and oxides of aluminum, although they are present in extremely small amounts, its effect on the properties of the melt are considerable.

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Among all gases that are normally in contact with aluminum, only hydrogen is soluble in a considerable degree. The nitrogen reacts with aluminum to form aluminum nitride (AlN), oxygen react to form aluminum oxide (Al_2O_3) and both are practically insoluble in aluminum. The main source of hydrogen in aluminum is water vapor which has the following reaction:

$$2Al_{(s)} + 3H_2O_{(v)} = Al_2O_{3\,(s)} + 6H_{(g)}$$

The hydrogen formed by decomposition of water is in atomic form and as such is soluble in aluminum. Its molecular form (H_2) is very slightly soluble. The water vapor is introduced through several sources, including:

- moisture from the refractory and wall ovens;
- humidity of the tools;
- humidity;
- water contained in fuels.

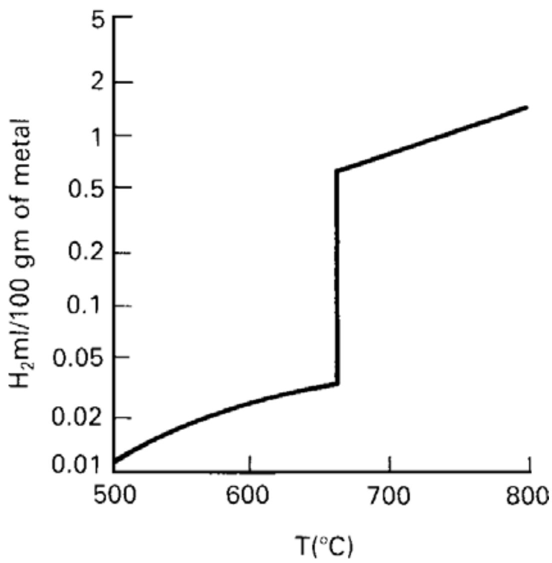

Figure 1. Solubility of hydrogen in liquid aluminum.[8]

There are numerous processes to evaluate or even measure the hydrogen content of samples in metallic alloys.

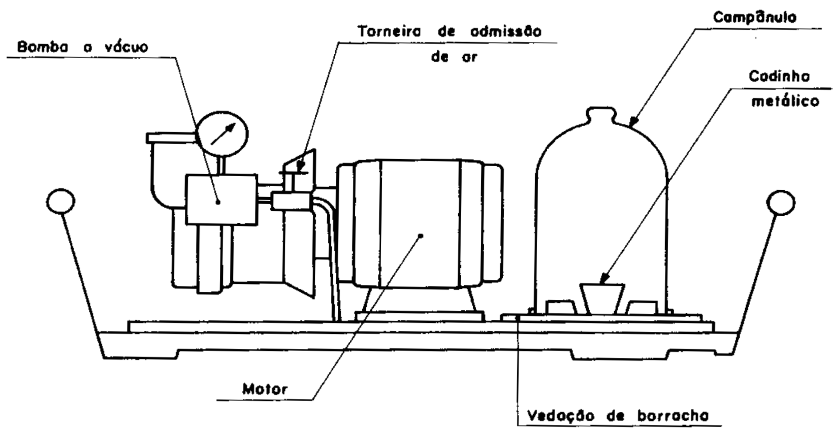

Figure 2. Scheme of a device solidifying under reduced pressure.[8]

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3.1.3 Method of detection and control of gas

One method is very common to solidify under reduced pressure,[4,5,8] where it is solidifying samples of approximately 130 g poured into a crucible wall thinly under a vacuum of 600 mmHg (Figure 2). The control of the quantity of gas contained in the metal cutting is performed by examining the sample and the presence or absence of voids due to hydrogen. It is also possible to have a precision of the exact amount of hydrogen gas dissolved in the alloy through the device "ABB Alscan Bomem" which performs the reading of the amount of hydrogen dissolved by introducing a probe into the liquid bath. The correlation between the density of the specimen and the amount of hydrogen dissolved in the alloy obtained by these methods described can be best viewed in Annex 1.

Cleaning the alloy can be achieved with the addition of flows on the surface of the liquid bath whose goal is to run the protection against oxidation and absorption of gases during preparation of the alloy liquid. These flows are a powder, chemical composition, variable which usually presents itself in the form of a salt.

3.1.4 The degassing

The degassing is to inject a flow of pure nitrogen through a metal lance connected between the side and bottom of the pan refractory (Figure 3) which is coupled in a porous refractory at the base of the pan. The function of moving the nitrogen is hydrogen particles are dissolved in the liquid bath. The salt is a flow used to protect against oxidation liquid bath, against the absorption of gases and to purify the bath of oxides and most of the gas it contains. It is very common to use these flows as liquid pool cleaner before casting parts that have a high severity level.

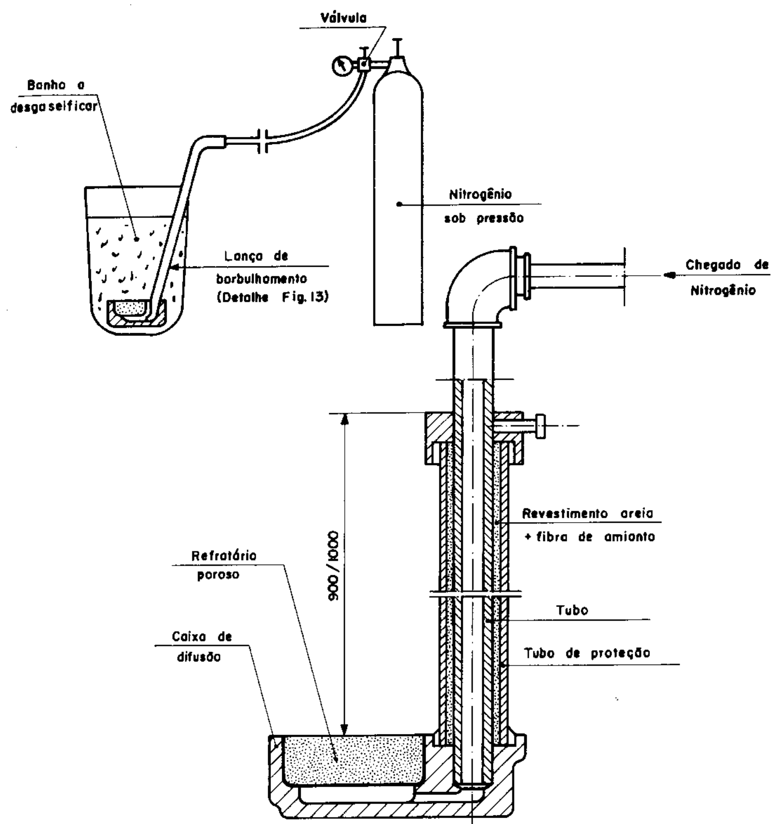

Figure 3. Operation of degassing with nitrogen.[8]

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4 MATERIALS AND METHODS

In this study experienced cleaning liquid alloy with flux containing salt the pans during the degassing with nitrogen (Figure 4) as the reference search suggest that the absence of a cleaning liquid alloy major factor in the formation of porosity in castings.[(1-4)] Degassing removes the gases present in the alloy during the preparation stage, while the flux containing salt used acts as a protector of the liquid bath, avoiding absorption of water vapor due to humidity, and consequently the hydrogen for subsequent nucleation porosity in the cast part. The production stage of preparation of the alloy liquid area (fusion) occurs before the transfer of power to the station waiting ovens leak parts (leakage area). In this workstation, called the treatment plant in the league, league degassing occurs in the pots and transfer cleaning liquid bath with flux containing salt. We decided to change the amount and form of flux containing salt adding, and salt is added preheated to eliminate moisture, the main source of hydrogen. The salt is placed in a container with continuous heating and positioned close to the treatment plant pots. Salt is added by a dosing own this workstation and is tipped with a ladle of steel during the alloy stage of degassing (Figure 5).

Figure 4. Pot alloy liquid transfer which runs degassing.

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Figure 5. Surface of liquid bath salt during the degassing.

The alloy samples were collected in the pots to assess by testing solidified under reduced pressure (Figure 6), the treatment efficiency fluxing salt preheated. The concentration of gases dissolved in the alloy can be measured indirectly by means of density, by weighing the specimens obtained during solidification of the test under reduced pressure. The control of the amount of gas dissolved in the alloy is made by cutting a sample (Figure 7) through its transverse axis after solidification and examining the number and size of the cavities (Figure 8) due to the presence of gas. The absence of cavities (Figure 9) on the sample surface cut and polished demonstrates the absence of gases dissolved in the alloy. The liquid alloy is treated after being transferred to spill area, where the parts are obtained from the engine head. The process of casting in molds is to pour the liquid alloy in metal molds, previously heated, as in sand containing male who had been previously prepared by core shop, which will form the internal cavities of the print head after the solidification and the extraction part in the area of the sand finish. After the sequence of casting, solidification, grinding and dimensional checks of routine, the head parts were inspected by X-ray control in real time and sent to the client application to perform the test for the engine machining and assembly.

Figure 6. Vacuum pump during the test solidification at reduced pressure.

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Figure 7. Extraction of the test piece from the mold after solidification of the sample.


Figure 8. Appearance of the specimen - liquid metal density: 2.70 g/c.c.


Figure 9. Appearance of the specimen - liquid metal density: 2.58 g/c.c.

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4.1 Parameters of the Experiment

- Temperature of the alloy into the furnace in the casting station: (700 ± 20)°C;
- Flux containing salt used: 2.6 kg of the VW 11
  Coveral Foseco pre-heated (60 ± 5)°C;
- Time degassing of the liquid alloy in the pot: 5 minutes;
- Initial Batch: 1000 parts of the engine cylinder head;
- Period beginning of the experiment: May 2, 2010;
- Head region to be evaluated in the presence of porosities: region in the face of the tappets will oil (Figures 10 and 11);
- Alloy AS7U3G (similar A319.0).

The table 1 shows the chemical composition of the alloy liquid used, similar to the ANSI 319 series.

Table 1. Mean chemical composition of the alloy liquid*

Al %	Si %	Cu %	Fe %	Mn %	Mg %	Zn %	Ti %	Na ppm	Ni %	Sn %	Pb %	Ca ppm	Cr ppm	Sr ppm
86.9	7.76	3.38	0.61	0.38	0.22	0.58	0.04	3	0.04	0.01	0.02	3	261	53

(*) Source: Quality Control in Brazil Teksid Aluminum - Laboratories

Figure 10. Face Head "raw" (identified within the circle region tappet cup).

Figure 11. Face head "machined" (identified within the circle region of the plunger cup).

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Note: "these pores are located in the region of the housing part in which the cup tappets, below the shoulder of the camshaft and above the valve spring. Because this head are mechanical tappets, this cavity contains no oil ducts and mechanical stress does not occur (the lubrication of the plunger-wall interface is made by the oil that drips from the camshaft)."

5 RESULTS

Table 2. Control the density of the liquid alloy in the pot with flux containing salt (*)

Date	Density (grams / c.c.)	Temperature (°C)
02/05/10	2,74	718
03/05/10	2,73	713
04/05/10	2,74	721
06/05/10	2,73	717
07/05/10	2,73	709
08/05/10	2,74	718
09/05/10	2,72	716
10/05/10	2,73	714
11/05/10	2,73	715
13/05/10	2,74	726
14/05/10	2,74	732
15/05/10	2,75	721
16/05/10	2,75	721
17/05/10	2,74	716
18/05/10	2,74	719
20/05/10	2,71	718
21/05/10	2,72	716
22/05/10	2,73	714
23/05/10	2,72	712
24/05/10	2,73	716
25/05/10	2,74	718
27/05/10	2,70	713
28/05/10	2,73	717
29/05/10	2,71	713
30/05/10	2,72	708
31/05/10	2,74	710

(*) Source: Quality Control in Teksid Alumínio do Brazil – Laboratories

Table 3. Index of rejection of parts after machining on the client*

Period	Number parts machining	Number parts rejects	% reject
January/10	20755	115	0.55
February/10	14186	92	0.65
March/10	18990	133	0.70
April/10	21268	191	0.90
May/10	20236	60	0.30
June/10	18162	43	0.24
July/10	19466	34	0.17

(*) Source: Quality Assurance in Teksid Alumínio do Brazil - Customer Assistance

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Table 4. Results of the density of the alloy in the pot with salt preheated

Date	Value of density alloy (grams /c.c.)	Surface of Specimen after solidification
02/05/10	2.74	
03/05/10	2.73	
04/05/10	2.74	
06/05/10	2.73	
07/05/10	2.73	

6 DISCUSSION OF RESULTS

We evaluated the performance of changes internally in the treatment of the alloy with flux containing salt by testing reduced pressure. This assay provides an indirect measure of the content of hydrogen dissolved in the liquid alloy, i.e., the porosity in castings. This measure is obtained through the density of the alloy during the solidification of liquid specimens. Table 2 presents the results of control during the experiment, such as: date of the experiment, the value of the density of the alloy removed the pan and the temperature of the alloy after treatment fluxing in the pan. It is noted in this table that the lowest density was 2.70 g/c.c. registered, on 27.05.07 (the 27th of May, 2007), and it is known that with this value, the amount of hydrogen

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gas present in the alloy is equal or liquid less than 0.07 c.c. of hydrogen/100 liquid alloy, i.e., there is no porosity in castings due to hydrogen. The gas level in the alloy (presence of porosities) was evaluated for surface appearance of the test piece cut off and measurement of density of the specimen shown in Table 4. In this table, it is observed that the cut and polished surfaces do not show any porosity. A lot of 1000 parts of the head just was inspected by X-ray optical control before being sent to the client for testing the engine machining and assembly. The control x-ray consists of a non-destructive testing with real-time image of the melt measured (Figure 12).

Figure 12. X-Ray (real time).

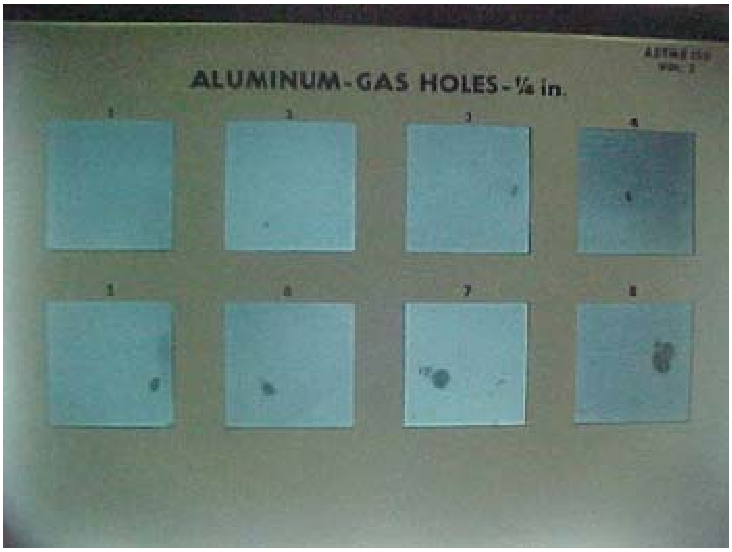

Figure 13. Standard ASTM E155.

This inspection can determine the rate of porosities, according to a standard ASTM E 155 (*) which contains pictures of the level of pores or gas bubbles (Figure 13) in molten aluminum. The diameter of a typical pore size is 112 microns (0.112 mm) on a surface polished and observed under an optical microscope (Figure 14).The results presented after the machining of the first batch of heads on the client, demonstrated the success of the test salt for the treatment of the alloy in the pot. This change in procedure also some improved flow properties of the alloy during mold filling in

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casting station to obtain the parts. This change in procedure for cleaning the liquid alloy was established as a routine work from the results of this initial batch machining. Subsequently, it was proven by a final machining of the change in the method of treatment was significant and can be better visualized by observation of Table 3. The reduction in the rate of rejection of castings had a positive economic impact on the results of the casting. The results obtained by machining the head parts of the client are in accordance with that provided for the articles (2, 3) found on the effect of cleaning liquid alloy in the formation of porosity in the cast components.(*) This reference shows the radiographic grades and types of discontinuities that might be found in molten aluminum and magnesium. Other factors can be studied in future to reduce the porosity in critical regions of the head. For example, the temperature gradient between the base head of molten metal within the mold and its feeder (reserve of liquid adjacent the connecting piece) which is also an important factor in the formation of pores. The geometric change in the profile of feeder this study may help to reduce porosity in certain regions of the head. For this purpose, should be used as a tool that allows a program used to simulate solidification, and thus to predict the occurrence of porosity in the upper parts of the engine head.

Figure 14. Pore diameter of 112.5 microns (0.1125 mm) observed with the optical microscope Olympus 100X.

7 CONCLUSION

To avoid the formation of porosity in castings should have a quality control of the processing liquid metal. This control must be cleaned with salt concentrate in pre-heated followed by degassing rotor. This type of control can minimize the porosity in castings, but can't eliminate them. Given this limitation, the relationship between the porosity in certain regions of the part and its function should be better analyzed by the designers during the commercial contract between the parties concerned to implement the project number, which today are considered: type of materials used, properties mechanical component in service (workpiece /machined dimensional

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tolerances of the design) and in the future should also consider the criteria of acceptability of this piece.

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ANNEX 1

Correlation (*) between hydrogen content and density of the liquid alloy

millimeter gases hydrogen (H_2) / 100 grams alloy	Density alloy (grams/c.c.)
< 0.070	> 2.70
0.077	2.69
0.084	2.68
0.091	2.67
0.098	2.66
0.105	2.65
0.112	2.64
0.119	2.63
0.126	2.62
0.133	2.61
0.140	2.60
0.147	2.59
> 0.154	< 2.58

(*) This correlation has been established by ABB BOMEM Spectrophotometer ALSCAN equipment belonging to the laboratory Teksid Alumínio do Brazil.

This device performs the reading of the amount of hydrogen dissolved the liquid alloy by introducing a probe into the liquid bath.

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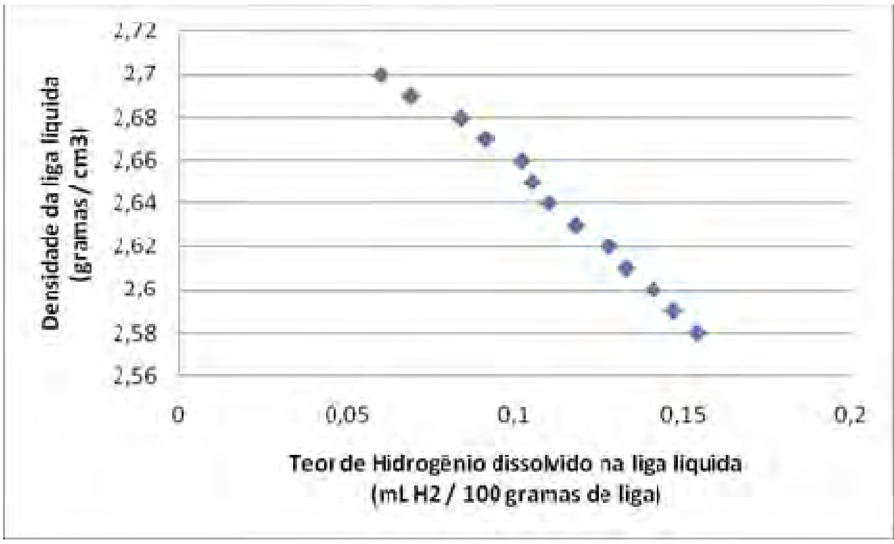

Figure 1. Correlation.

ANNEX 2

Figure 1. Equipment ALSCAN the Bomem.

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ANNEX 3 - DEFINITIONS

Head for a Motor: is normally aluminum, which closes the top of the cylinder, and in which are housed the valves, rocker arms, the inlet and outlet collectors of the combustion chambers and pipeline network which cools the motor, and the valve camshaft.
Liquid On: is a physical system containing more than one chemical element, and is at least one metal.
Feeder: reserve liquid metal, adjacent to the piece, whose goal is to provide liquid metal to compensate for the contraction in the liquid during solidification. Metal mold, in metal form is introduced pasty or liquid material, which solidify to take certain way.
Porosity: voids are castings, cavities can be superficial, subcutaneous or internal, form, size and distribution variables, caused by the contraction of the liquid metal associated with segregation of hydrogen and difficulties filling.
Shrinkage: they are devoid of many types, shapes and locations in castings caused by contraction of the metal during its solidification.
Simulator Solidification: software that simulates the solidification of the alloy, considering all the factors that directly interfere with the solidification of the alloy.