Origin of the Liquid Hot Isostatic Pressing Process

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INTRODUCTION

In the late 1980s, when the author was president of Metal Casting Technology, Inc. (MCT), a joint venture proccess development company between Hitchiner Mfg. Co., Inc. and General Motors, a new low cost casting process for titanium alloys was invented and later patented, US 5,299,619. 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 anticipated for the new low cost casting process. As a result of this need, the author devised an approach using mechanical means to pressurize a non-reactive molten salt, which in turn, pressurized the casting surface, closing interna l porosity. This brief article describes some of the early work which led up to the patenting of the Liquid Hot Isostatic Pressing (LHIP) process as disclosed in US Patent 5,340,419.

APPROACH AND RESULTS

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. Reference one is an excellent article with some other references for anyone desiring more information about gas HIPping. 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 at temperature and pressure was on the order of 15 to 30 seconds, an approach like that in Figure 1 might be feasible. First, a pressure vessel containing molten salt, first view in the upper left of the figure, would be maintained at a temperature, say 550 °C, for which a number of alloys have adequate strength to sustain up to1650bar (25,000 psi). Second, a container with a higher temperature salt and the parts to be LHIPped, second from upper left view, would be heated separately to the desired LHIP temperature. Third, the hot container with parts and salt, third from upper left view, would be placed in the lower temperature salt. Subsequent steps to the right upper and left to right on the lower views as described would have to be done rapidly, before the hot salt surrounding the parts was cooled significantly by the lower temperature salt.

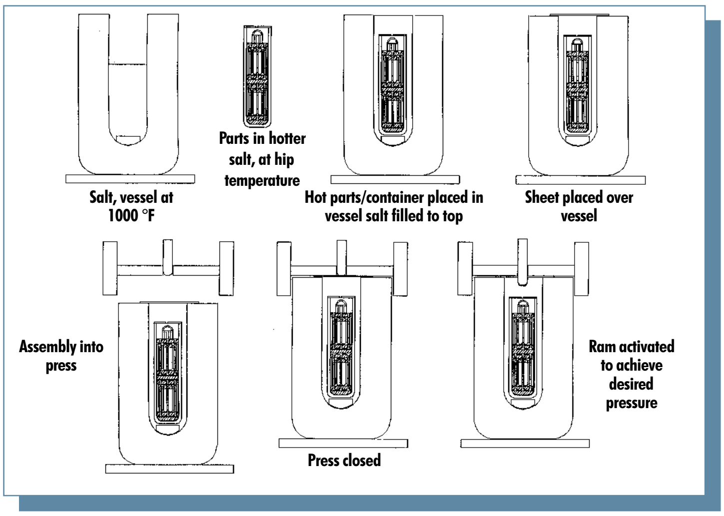

Fig. 1: Steps in the LHIP process

Armed with the optimism required in all development, we set up an old hydraulic press, and cast a small pressure vessel in INCO 713. It had inside dimensions of only about 100mm diameter and 250mm deep. The press had a 50mm ram to apply pressure. Many small castings of plain steel, stainless steel, titanium, nickel alloys, aluminum alloys, and malleable iron were run through the small vesse l. When aluminum was done, it was not necessary to use a separate container as shown in Figure 1, as the salt in the pressure vessel was kept at the desired LHIP temperature. The cooling curves when doing high melting point alloys were measured and found to be fairly quick, but even in these small containers, there was adequate time to completely close the porosity in the alloys shown. This, of course, was great news since scaling the vessel up to larger sizes would make the cooling of the hot salt less of a problem.

The vessel was scaled up to the largest size we could reasonably handle, inside dimensions of 250mm diameter and 400mm deep. In scale up, a variety of mechanical problems were encountered with the old press, but only two relating to the process itself will be discussed. First, although most of us had remembered from early physics that liquids were incompressible - in the rea l world, it turned out that liquids are indeed compressible at high pressure. Our salts compressed some 4%, with the larger pressure vessel, this used up too much of the displacement of our 50mm ram, so the press was modified to provide a 100mm ram. Using copper sheets for the top pressure vessel seal enabled us to LHP many more and larger castings of all of the above alloys. Mechanical testing gave results in fatigue of aluminum and malleable iron that were very impressive, as shown in Figures 2 and 3. Of most interest was cast aluminum, for which the endurance limit was improved almost 100%. These data were from actual castings. For shaped aluminum castings, it was necessary to add hydrogen to the melt before casting to assure the absence of surface connected porosity in the casting. It was found in casting aluminum that almost any isolated boss would have some surface connected shrinkage and would be impregnated with salt during LHIP. Adding the hydrogen before cast to counteract shrinkage also enabled significant reduction in gating, especially when countergravity casting. Parts such as suspension arms and steering knuckles were satisfactorily countergravity cast and LHIPped with only 1'/o gating weight when the hydrogen was properly added to the melt. Semi-permanent molded aluminum castings always contained surface connected porosity on the sand core surface unless hydrogen was added. It was also found that adding hydrogen to semi-permanent molded castings did not always result in the uniform distribution of hydmgen bubbles as was found in sand castings (Reference 2). Also, many aluminum die castings were LHIPped; it was a pleasant surprise to us that this solved major problems with after machining leakage and low thermal conductivity due to internal porosity as cast. No problem was found with blistering of the die castings due to LHIP.

Penetrant inspection of the sample parts was always required when setting up foundry practice to assure there was no surface connected porosity in the approved practice and to yield optimum parts after LHIP. This practice not only yielded parts with high fatigue properties for alloy 356 as shown above, but also very good tensile properties from sand cast alloy 356 parts in 18 mm thick

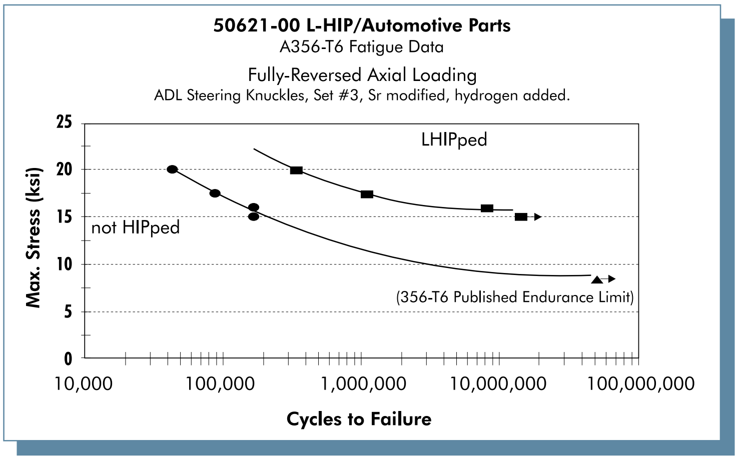

Fig. 2: Some fatigue properties of aluminum castings

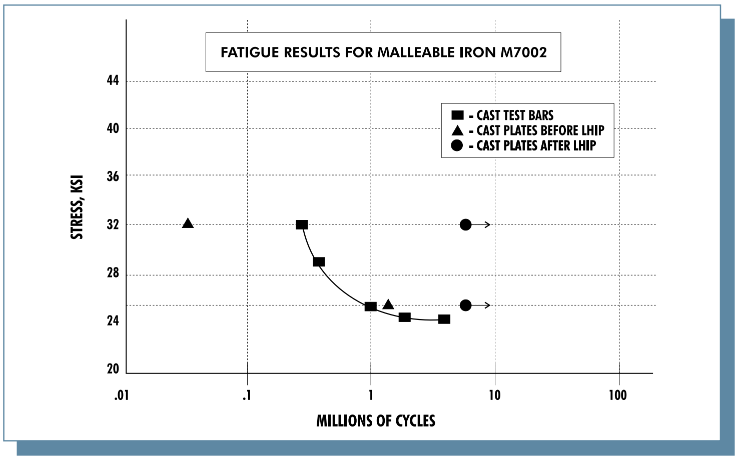

Fig. 3: Some fatigue properties of malleable iron castings

sections as follows (average and range ()[ ] for five tests):

Yield Strength,ksi,[MPa]	Tensile Strength,ksi,[MPa]	% Elongation
39.4(39.1-39.9)[269-275]	29.1(27.2-30.5)[187-210]	7.7 (6.2-9.1)

Note: parts were quenched from LHIP temperature and aged.

It is interesting to note that some premium quality specifications for alloy 356 require higher yield and tensile strengths than those in the table. In most casting thicknesses, those higher strengths require the use of structure modification and/or rapid cooling (chilling) to round the eutectic particles and refine the structure to give improved response to heat treatment. In the above test results, peak strengths were not reached as peak aging could not be achieved with the segregated structure in the slow cooled sand castings. Other test bars that were solution treated and aged after LHIP did not show tensile properties better than the above. However, the soundness created by the LHIP did give fine tensile properties overall with both methods.

The other mechanical problem related to the process was that the copper sheets did not always seal the ram from the salt. Also, the cost of the sheets was significant. Thus, the press was modified so the grease around the ram in the top platten of the press could be pressurized to the same level as the salt pressure. This eliminated the need for the copper sheets. Other liquids have been used successfully to overcome this difficulty as well.

FUTURE OF LHIP

Teksid and IDRA have taken LHIP far beyond the early work at MCT. They have overcome many problems of scaling up to sizes that accommodate engine heads and blocks. Certainly the future af LHIP to do aluminum castings should be bright, as it seems to be the only known, potentially economic way which can upgrade aluminum castings to the degree needed for safety and other high quality parts for automotive applications.

REFERENCES

1. Robert Widmer, "The Current Status of HIP Technology and Its Prospects for the 1990's", Fourth Annual Conference on Isostatic Pressing, Stratford-Upon-Avon, U.K., November 5,6,7 1990.
2. P.H. Mikkola, J.R. Redemske, "Optimizing the Properties of Cylinder Heads Cast of Aluminum", SAE Paper 940153, February, 1994.

ACKNOWLEDGEMENT

It gives me great pleasure to acknowledge the enthusiasm and dedication of MCT, Teksid and IDRA to making this new process work. My best wishes to all for a great success!