**CAST 625 HOT ISOSTATIC PRESSING (HIP) PARAMETERS -
A STATISTICALLY DESIGNED STUDY**

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ABSTRACT

Cast-to-Size bars of IN625 castings were processed in the statistically designed Hot Isostatic Pressing (HIP) program, which investigated a total of nine HIP parametric conditions. Quantitative evaluation of the x-ray CT (Computer Tomography) indications depict decreasing CT defects with increasing HIP temperature. Tensile test results reveal effects of the HIP temperature on cast 625's 0.2% yield strength, ultimate tensile strength, reduction of area, and elongation. By superimposing the reduction of area and the elongation plots over the ultimate and yield strength plots, they appear to cross over at about 2050°F. Computer models for the HIP process have been generated. Metallographic characteristics of these cast bars confirm the ability to seal seeded defects.

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INTRODUCTION AND BACKGROUND

Investment castings of a wide variety of sizes are being used on aircraft and rocket engines. The demand for higher performance engines puts limitation on successfully applying these structural castings. Hot Isostatic Pressing (HIP) provides a means of sealing casting porosity and improving properties. Ideally, castings should be fully dense; but they are not. HIPing clearly improves structural castings. The ability to HIP such structural castings provides for decrease in voiding (inherent in most castings) often with strength increases and property scatter decreases. Two hallmark characteristics of a HIP product are the yield strength and the reduction of area.

The trust of this program has been to develop low cost rocket engine components. One such component is the nozzle support. Currently it is a forged IN625 part, and the intent is to reduce costs and manufacture this part from a casting.

As part of the program, IN625 HIP parameters are to be developed. This has been accomplished in an experimentally designed test matrix, in a manner similar to earlier heat treat studies ⁽¹⁾. The approach employs a central-composite design to investigate two or three continuous variables on performance characteristics. Prior to performing these tests it had been necessary to validate the planned approach with a vanguard experiment on a Rene'220C cast slab containing seeded holes, which were detected by computer-aided tomography. This approach allows radiographic examination in planar "slices" that are then developed into a stack of continuous layers creating a three-dimensional image. The same general principles govern the use of computer-aided tomography in the medical field commonly referred to as "CAT Scan". A similar procedure was used to study HIP densification of cast IN718 ⁽²⁾. The vanguard results on Rene'220C are documented in a separate report ⁽³⁾. In this, cast IN625 specimens, produced at PCC, Portland, are HIPed under statistically designed processing conditions and evaluated as described below.

APPROACH

MATERIAL AND PREPARATION

Initially the IN625 specimen blanks were to be cast slabs, but the delivered plates were too thin (only about 1/4 inch thick). As a result, cast-to-size tensile blanks were evaluated. Twenty IN625 cast-to-size blanks were received from PCC/LSBO, Portland. The PCC Invoice number was 13185, while the Metal Lot number was 32059. These specimens were subject to FPI inspection for surface defects and no defect areas could be detected. The chemistry shows that the material meets specification requirements.

To produce the artificial holes in these specimens, an EDM drill/EB weld sealing technique, previously developed was employed. In this procedure the holes, approximately 1/16 inch in diameter were EDM along the specimen axis. Each hole was carefully inspected and then etched to remove all traces of the copper drilling tool. The holes were then sealed by placing them in a rotation fixture, and EB sealing the holes under vacuum. All specimens were found to be leak-free after an argon pressure check. The specimens were then examined by x-ray CT.

X-RAY COMPUTER TOMOGRAPHY (CT)

Computer-aided tomography is applicable to all types of materials and allows radiographic examination in planar "slices" that are then developed into a stack of continuous layers, which create a three-dimensional image. The x-ray source can be rotated about the specimen and penetrate from many angles to provide a global view. This then allows reconstruction of cross-sectional images of the object. The same general principles govern the use of computer-aided tomography in the medical field commonly referred to as "CAT Scan".

One of the slices, magnified 8 times in Figure 1, clearly reveals the hole's uniformity and symmetry. One unHIPed specimen and 14 specimens subjected to a statistically designed series of HIP cycles, were again examined by CT x-ray evaluations.

FIGURE 1. X-Ray CT Indication of a Sliced Section of The Sealed Hole After Electron Beam Welding.

STATISTICALLY DESIGNED HIP CYCLE

The cast-to-size bars were autoclaved in EMTL's Conaway/IPS 4 inch HIP facility located in Building 500. A total of 14 specimens were HIPed under argon in a Central Composite Experimental Design. With these conditions, the center point was 2000°F for temperature and 3 hours for time. A total of 9 HIP parameters was evaluated with 6 runs at 2000°/3 hours. In all cases the HIP pressure was 15 ksi. HIPed test specimens were then machined and room temperature tensile tested and metallographically examined.

RESULTS AND DISCUSSION

X-RAY CT

The results on all specimen CT indications, before and after the HIP cycle, are given in Table I. The CT indications, as a function of HIP temperature, seen in Figure 2, clearly show decreasing values as HIP temperatures increase. It appears that the 2050°F/4Hour HIP cycle shrinks defect indications to less than 0.1X. A multiple regression analysis related the dependent variable of percent defect indications with the independent variables of HIP time and temperature. A contour plot of the analysis representing the model is shown in Figure 3. This model depicts zero defects with a 2050°F/4Hour HIP cycle.

TENSILE TESTING

The one as-cast and the 14 HIPed specimens were machined to the tensile test configuration. The machined specimens were room-temperature tensile tested at a strain rate of 0.005 in./in./min. through the 0.2% yield and then at 0.05 in./in./min. to failure. Table I presents these data.

TABLE I SUMMARY OF HIP PARAMETERS WITH TENSILE AND CT RESULTS

Cursor at Row: 1				Cursor at Row: 1				Data Editor		Maximum Rows: 14	
Column: 1				Column: 9				File: HIP625		Number of Cols: 9	
Row	T_HIP	time_HIP	Spec_No	NDT_perc	UTS_ksi	YS02_ksi	YS2_ksi	EL_perc	RA_perc		
1	1950.	2.0	2.	15	95.5	39.1	46.2	51.1	45.1		
2	1950.	4.0	3.	10	93.7	36.3	41.8	49.1	43.5		
3	2050.	2.0	4.	5	94.4	34.6	41.0	55.1	46.1		
4	2050.	4.0	5.	0.1	93.0	35.5	40.3	55.2	48.0		
5	2000.	3.0	6.	8	96.5	36.0	42.3	55.3	48.4		
6	2000.	3.0	7.	8	86.0	35.0	39.4	47.2	55.3		
7	2000.	3.0	9.	6	91.4	34.7	40.7	48.7	53.5		
8	2075.	3.0	10.	0.05	93.8	36.7	40.6	61.8	52.3		
9	1925.	3.0	11.	10	100.2	37.9	44.2	60.0	46.1		
10	2000.	4.5	13.	4	89.9	34.4	40.3	50.4	47.4		
11	2000.	1.5	14.	10	99.4	37.4	43.3	59.1	54.4		
12	2000.	3.0	15.	8	94.6	39.3	42.4	61.2	48.6		
13	2000.	3.0	16.	8	99.7	37.6	43.9	66.6	52.4		
14	2000.	3.0	19.	7	95.8	35.6	41.2	60.4	51.6		
15	NO HIP	0.0	18	100.0	95.4	44.2	49.6	48.4	45.5		

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FIGURE 2. X-Ray CT Indications (%) As a Function of HIP Temperature.

FIGURE 3. Contour Plot of X-Ray CT Indications (%) As a Function of HIP Temperature And Time.

Figure 4 and 5 reveal the effect of the HIP temperature on, respectively, the 0.2% Yield Strength and the Ultimate Tensile Strength. The data were analyzed by a least square statistical evaluation. In both cases strengths gradually fall with increasing HIP temperature. To model the HIP process with respect to the yield strength, a multiple regression analysis of the 0.2% Yield Strength and the HIP parameters was performed. The HIP process model, in the form of a contour plot, is shown in Figure 6. A yield strength transition occurs at about 2050°F/4Hour. This model suggests that lower HIP temperatures produce higher yield strengths.

FIGURE 4. Tensile 0.2% Yield Strength As a Function of HIP Temperature.

FIGURE 5. Ultimate Tensile Strength As a Function of HIP Temperature.

FIGURE 6. Contour Plot of 0.2% Yield Strength As a Function of HIP Temperature and Time.

Figure 7 and 8 show the effect of the HIP temperature on the reduction of area and the percent elongation. Here ductility behavior increases with increasing HIP temperature. Not too surprising, since voids diminish with the higher HIP temperatures. Note from Table I that the as-cast reduction of area and elongation are consistently low. A multiple regression analysis was performed on the reduction of area with the HIP parameters. These results allowed the generation of a contour plot shown in Figure 9. This plot reveals a reduction-of-area maxima at about 2025°F/3 Hours. In statistical design parlance, a maxima represents a "robust" design point, since it would offer an optimized process parameter to minimize property loss from "noise" variations in the independent processing variables.

By superimposing the Reduction of Area and the Elongation linear plots over the Ultimate Tensile Strength and the 0.2% Yield Strength plots, they appear to cross near 2050°F.

FIGURE 7. Tensile Reduction of Area As a Function of HIP Temperature.

FIGURE 8. Tensile Elongation As a Function of HIP Temperature.

FIGURE 9. Contour Plot of Tensile Reduction of Area As a Function of HIP Temperature and Time.

METALLOGRAPHY

EDM drilled holes were examined before and after HIPing. From the prior-to-HIP structure, shown in Figure 10, several observations can be made. As noted, the EDM hole is quite symmetrical, with a diameter of about 0.075-inch. Evidence of a recast layer can be readily detected even at 100X. The structure away from the hole clearly shows the dendritic feature, along with the microporosity evident in as-cast materials. Similar structures were observed in Cast 718⁽⁴⁾. Able efforts were expended in detecting these collapsed-holes after the HIP cycle. Examinations on the unetched specimens failed to locate these areas. A typical etched structure after the HIP cycle can be seen in Figure 11. In all cases, the metal flows into, and seals the seeded holes.

FIGURE 10. As-Cast IN625 Prior To HIP Showing the EDM Hole (Top-40X), the Recast Region (Middle-100X), and Typical Porosity (Bottom-100X).

FIGURE 11. Metallography of Collapsed-Hole Area After a HIP Cycle At 2075°F/3Hours (Top-40X and Bottom-100X).

CONCLUSIONS

1. Computer-Aided-Tomography (CAT) scan indications revealed that seeded defects in IN625 castings are completely eliminated after a 2050°F/4Hour HIP cycle.
2. Tensile results show yield strengths monotonically decrease, while reductions of area increase as HIP process temperatures rise.
3. Statistically developed HIP models of the dependent variable of reduction of area indicate a "robust" region at the HIP parameter of about 2025°F/3Hour, while the model for the yield strength shows a transition at about 2050°F/4Hour.
4. The recommended HIP processing parameter for cast IN625 is 2050°F for 4 hours at 15 ksi.

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