HIP'ING VARIOUS PRECISION CAST ENGINE COMPONENTS IN NICKEL-BASE SUPERALLOYS.

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In addition to microporosity closure, hot isostatic pressing can impart nickel-base superalloy engine components improved microstructural features as compared to those of their as-cast counterparts, provided the cycle parameters have been carefully optimized. In that connection, the cooling rate after the HIP dwell period can be of major importance. The process not only increases the parts'performances, but also improves their reliability through reduced property scatter. Advantages can also be derived from simplified ultimate thermal treatments, reduced scrap rates, and better use of the superalloy barstock. Well suited processing and technological precautions moreover lead to high dimensional and surface quality. The paper aims at contributing to the knowledge of the metallurgical effects of HIP on various nickel-base superalloys : IN 713 LC, IN 792 + Hf, Mar-M-002, Mar-M-004 and IN 100.

INTRODUCTION.

Hot isostatic pressing (HIP) consists of a thermal cycle which parts undergo while they are subjected to a high gas pressure. It has been applied to jet engine parts made of a wide variety of alloys to heal various casting defects (1 to 6).

Full densification of nickel-base superalloy castings through porosity closure by creep deformation and diffusion bonding can only be obtained easily in the temperature range between gamma prime solvus and incipient melting point, because of reduced creep resistance and enhanced atomic interdiffusion. If the upper limit of that range were exceeded, oxidation rates would increase exponentially and the dimensional quality of the HIP'ed parts would be jeopardized (1). It has however been made clear that HIP conditions should be carefully adjusted to each alloy (1, 4, 5), but even in that case, post HIP heat treatments are often necessary to give nickel-base superalloy castings such a microstructure as to lead to comparable or even substantially improved engineering properties, as compared to their cast (and eventually heat treated) counterparts (1, 3, 5, 6). Hot isostatic pressing also brings about an increased structure and chemistry homogeneity which makes the ultimate chemical milling and welding operations much easier (4, 7). It can furthermore contribute production cost reduction through savings on the casting procedure and scrap rate decrease (3, 5, 6).

HIP has also been envisaged as a means to rejuvenate used engine parts, but new cycle conditions, sometimes much different from those well suited for as-cast parts, must then be worked out to take into account the actual nature of the service damage to be healed (8, 9).

This paper aims at contributing to the metallurgical knowledge that has been gained so far on HIP'ed castings. It is based on experimental results which were obtained over a period of two years, using a graphite furnace-heated Autoclave Engineers press allowing very high cooling rates, and other slower cooling, molybdenum tubular resistance- heated HIP presses. The technical information that follows is related to turbine blades or integral wheels made of various nickel-base superalloys : IN 713 LC, IN 792 + Hf, Mar-M-002, Mar-M-004, IN 100...

MAIN EFFECTS OF HOT ISOSTATIC PRESSING

a. Microstructure

Fig.1 shows that hot isostatic pressing can lead to a substantial decrease in the microporosity contents of Mar-M-004 blades, provided it is carried out at sufficiently high temperature and/or pressure. Those microstructural features from which good engineering properties derive must however be achieved at the same time. Such a result can only be obtained through careful HIP cycle fitting, taking into account the effect of every parameter on the particular alloy being treated, especially that of the cooling rate after the HIP dwell period (10). The latter must in fact be high enough and in our case, it could almost reach 1000°C/h (1800°F/h) between

1220°C (2230°F) and 650°C (1200°F).

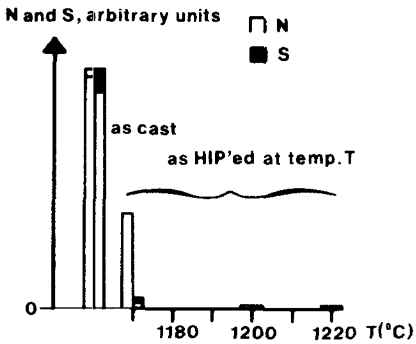


Fig.1.a.
Mar-M-004 : Evolution of porous area number, N, and total porosity surface, S, with HIP conditions.

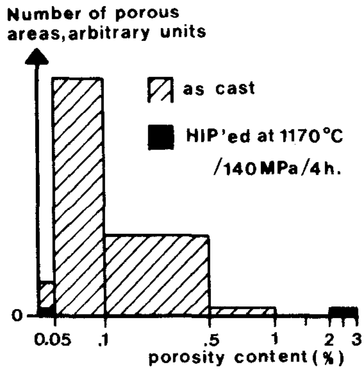


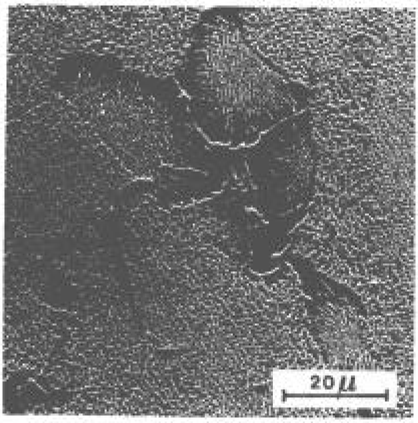
Fig.1.b.
Mar-M-004 : Porosity grading in various conditions.

Rapid cooling may nevertheless lead to inhomogeneous ultimate microstructures, as can be seen in Fig.2 in the case of IN 100 turbine blades. The latter consistently exhibit altered eutectic morphology and sometimes, heterogeneous second phase particle distribution. It is worth noticing here that although it usually contributes but a minor microstructural effect, higher HIP pressure in this case actually helps homogenize the gamma prime distribution. If the cycle temperature is too high, partial carbide dissolution may also take place, without its being possible to reprecipitate properly, as shown in Fig.3 for Mar-M-002 blades HIP'ed at 1220°C (2230°F), under 140 MPa (20 ksi).

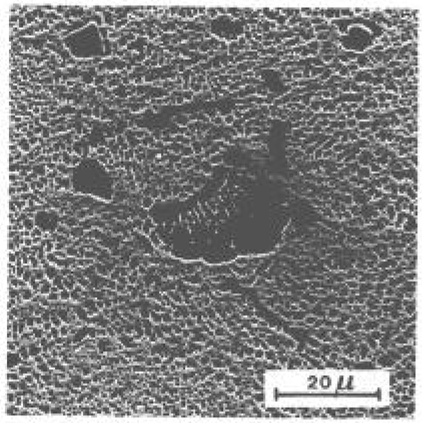
b. Properties

Optimized HIP cycle conditions, based on the above mentioned principles, can usually be worked out to substantially improve the engineering properties of turbine components. This can be seen in Fig.4 for as HIP'ed and chromaluminized IN 713 LC blades which exhibit much better creep properties than their as-cast counterparts. Their microstructure is such that a post HIP ageing treatment (930°C (1700°F)/16hours/air) may even deteriorate the high temperature creep lives.

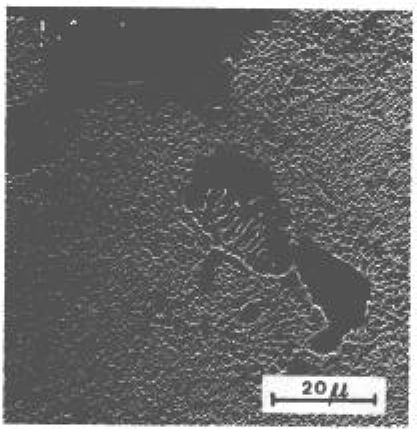
Well suited hot isostatic pressing cycles not only increase both minimum and average property values but can also significantly decrease the corresponding statistical scatter, as is shown in Fig.5 for Mar-M-002 blades. This obviously improves the part's practical reliability.



as-cast



as HIP'ed at 1220°C (2230°F)/ 100MPa (15 ksi)/4h.



as HIP'ed at 1220°C (2230°F)/ 140 MPa (20ksi)/4h.

Fig.2.
IN 100 blades : Influence of HIP conditions on eutectic morphology and γ' particle distribution

COROLLARY EFFECTS OF HOT ISOSTATIC PRESSING.

If carried out at a high enough temperature, HIP cycles can lead to chemistry homogenization without deleterious second phase coarsening, provided the cooling sequence is sufficiently rapid.

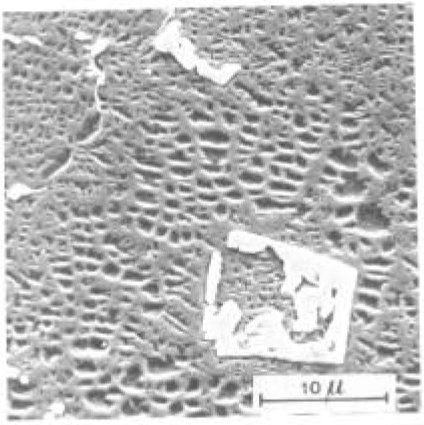


Fig.3. Mar-M-002 : Carbide partial dissolution during HIP at 1220°C/140MPa/4h.(2230°F/20ksi/4h).

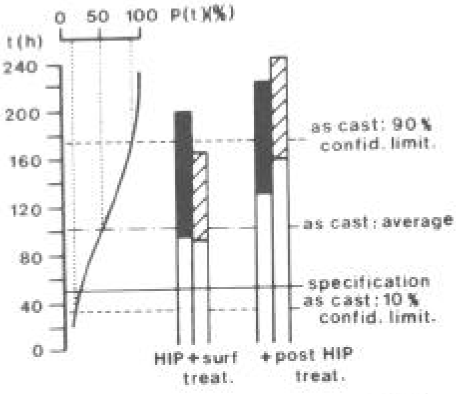


Fig.4.a. HIP'ing IN 713 LC blades : creep life at 760°C/ 530MPa (1400°F/77 ksi).

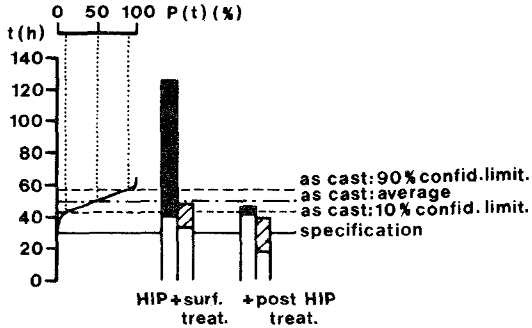


Fig.4.b. HIP'ing IN 713 LC blades : creep life at 980°C/ 150MPa (1800°F/22 ksi).

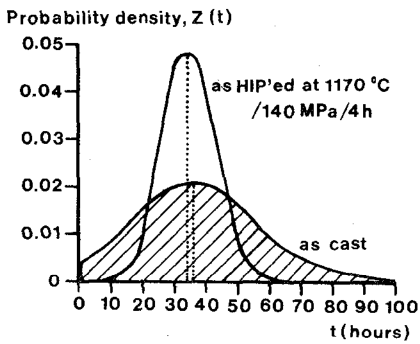
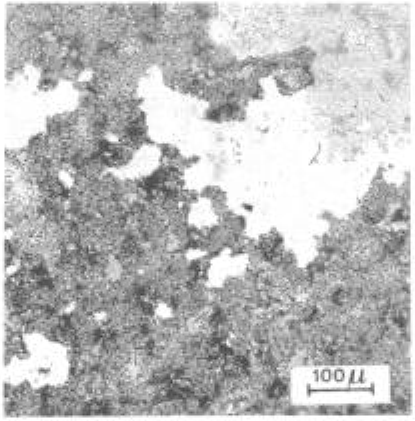
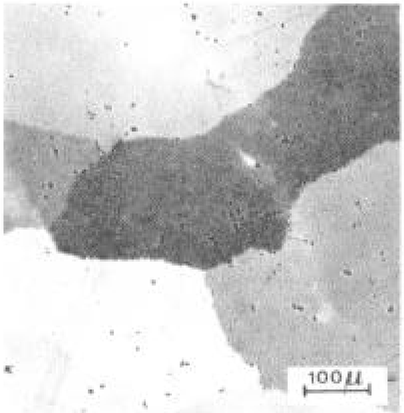


Fig.5. Mar-M-002 : Influence of HIP on the probability density function of creep lives at 760°C/695MPa (1400°F/100ksi).

This can be seen in Fig.6 for Mar-M-004 blades. Practical advantage can be derived from that structural effect for those alloys which are to be used in the heat treated condition. In that connection, Fig.7 shows that HIP'ed IN 792 + Hf (C101) integral wheels, solely subjected to a 2 step ageing treatment (840°C (1540°F)/4h/air, and 760°C (1400°F)/16h/air), exhibit high temperature creep properties comparable to those of identical cast parts which underwent the complete 3 step heat treatment (1120°C (2050°F)/3h/air + 2 step ageing).





HIP'ed at 1170°C (2140°F)/ 140MPa (20 ksi)/4h

HIP'ed at 1220°C (2230°F)/ 140MPa (20 ksi)/4h.

Fig.6. Mar-M-004 blades : Influence of HIP conditions on dendritic segregation.

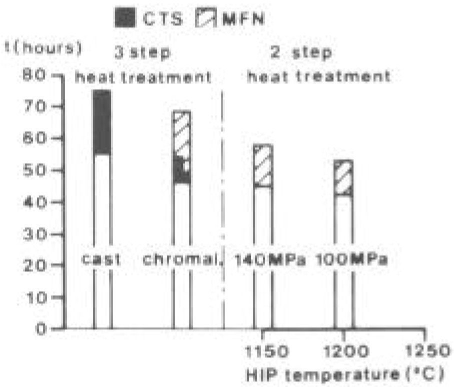


Fig.7. IN 792 + Hf wheels : effect of simplified thermal treatment on the creep lives at 980°C/200MPa (1800°F/30 ksi) of HIP'ed parts.

HIP also helps better use the superalloy barstock as it confers those parts cast in revert material ultimate properties equivalent to or better than those of parts made of virgin metal. This is evidenced in Fig.8 for Mar-M-002 blades which exhibit poor creep lives when cast in revert metal, but are amenable to substantial improvements through HIP processing which brings the minimum life well beyond that required by the engine designer, however bad the as-cast revert metal may have been.

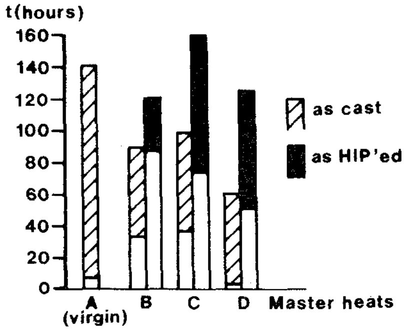


Fig.8. Mar-M-002 : effect of HIP on the creep lives at 760°C/695 MPa (1400°F/100 ksi) obtained with various master heats (HIP conditions : 1220°C (2230°F)/ 100MPa (15 ksi)/4h).

TECHNOLOGICAL ASPECTS

Numerous tests showed that full metallurgical advantage can be drawn from hot isostatic pressing, without impairing the dimensional quality of the HIP'ed articles. Optimized cycle parameters can indeed be worked out, and appropriate part fixtures can be used that leave the HIP'ed parts with the same shape and dimensions as in the as-cast condition. No pattern injection die modification would then be needed if hot isostatic processing were to be used in production.

Severe oxidation, with local gamma prime dissolution, alumina precipitation and overageing was sometimes observed in HIP'ed nickel-base superalloy blades. It must however be pointed out that practical précautions can make those defects hardly detectable or easily removable through soft sand blasting : pressure vessel purification and protection, part cleaning (eventually by heat treatment under vacuum) and conditioning, use of very pure argon gas (molecular filtering,...). Fig.9 illustrates the adequate ultimate surface condition that can be obtained in the case of IN 713 LC HIP'ed blades. In actual fact, even particularly reactive metals can thus be treated without any surface damage, since as HIP'ed Ti6Al4V parts exhibited exceptionally low oxygen, carbon and hydrogen contaminations (0.3%, 0.12% and 0.003% respectively, as compared to 0.2%, 0.06% and 0.004% before HIP'ing).

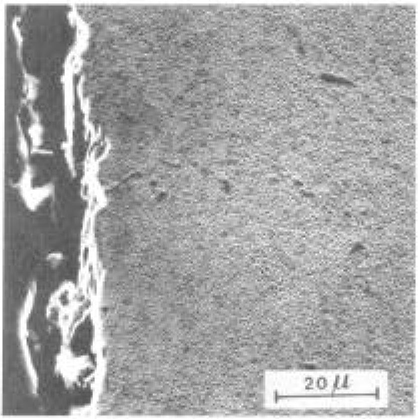


Fig.9. Good surface quality obtained through soft sand blasting on blades HIP'ed in appropriate conditions.

CONCLUSIONS

The authors'experience suggests that HIP processing can give nickel-base superalloy engine components such microstructural features as to substantially improve their engineering properties, even in the absence of any post HIP heat treatment. In that connection, the cooling rate after the HIP dwell period is of major importance. The process not only increases the parts'performances but also improves their reliability by reducing property scatter.
Moreover, it contributes to production cost decrease by making it possible to simplify the ultimate heat treatments, reduce the scrap rate, and help better use the superalloy barstock. Good processing and practical precautions also lead to high dimensional and surface quality.

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