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EFFECT OF HIP PARAMETERS ON MICROSTRUCTURAL REPAIR AND REJUVENATION IN LONG-TERM SERVICED SUPERALLOY TURBINE BLADE, IN-738

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ABSTRACT

The purpose of the present work is to obtain the most suitable and practicable repair-condition, which provides the optimal microstructural characteristics by the rejuvenation method of hot isostatic pressing (HIP) followed by the heat-treatment process for long-term exposed gas turbine blades, casting nickel based superalloy grade IN-738, after 70,000 hours-service operated by the Electricity Generating Authority of Thailand (EGAT). The hot isostatic pressing could mostly heal any internal structural voids, which were generated during service, by means of sintering. Furthermore, during solution treatment, coarse carbides and gamma prime precipitates, which formed previously at the grain boundaries during service, would dissolve into the matrix. Then the specimens will be processed through a series of aging cycles, which re-precipitates the strengthening phase to form the proper microstructure that is almost similar to the new one. Metallurgical examination of the microstructure will be performed by utilizing an optical microscope and scanning electron microscope after hot isostatic pressing and heat treatment to evaluate the microstructural evolution.

Keywords: Hot Isostatic Pressing (HIP), Rejuvenation, Microstructural Repair, Nickel-Based Superalloy

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INTRODUCTION

The service life extension of gas turbine components is becoming increasingly important, especially with nickel-based superalloy turbine blades and vanes. At present, their production-costs are becoming much higher due to the complex process conditions and expensive alloying elements. Therefore, it is very important to determine the rejuvenation method for the nickel-based superalloy components after long-term services at high temperature. In the case of conventional casting superalloys, the creep damage occurs firstly as the microstructure changes such as coarsening and coalescence of gamma prime precipitates, which is then followed by void formations typically showing up at grain boundaries. Thus, a classical hot isostatic pressing (HIP) is required to eliminate the creep damages (Sims, *et al.* 1995; Tien, *et al.* 1989; and Donachie, *et al.* 2002).

Hot isostatic pressing (HIP) offers the possibility of eliminating closed porosity, voids and creep voids in cast components. HIP is able also to improve the homogeneity of the microstructure, both by dissolution of segregates and by the elimination of porosity, as well as the material properties. This is especially important in the case of cast parts, which are subjected to very high stresses, such as turbine blades made of nickel based superalloys. Turbine blades for aircrafts and stationary gas turbines are among the first applications of HIP to cast products (Daleo, *et al.* 2002; Wangyao, *et al,* 2004; Wangyao, *et al.* 2004, Wangyao, *et al.* 2004). Furthermore, HIP is also utilized both for the improvement of weld or braze material (porosity removal and improved bonding) and for the removal of creep porosity development during previous service in the area of turbine blade rejuvenation.

The blades or vanes are processed at solution temperature under very high pressures in an inert gas environment. The process could heal any internal structural voids or porosity and prepare the material for heat treatments. In a furnace, the blades or vanes are held at the solution temperature, which causes the coarse carbides, gamma prime, and gamma double prime, to be formed at grain boundaries during service, and be dissolved in the matrix.

According to previous work (www. liburdi.com), the rejuvenation process provides blades to double and in some cases, triple the lifetime as compared to the original ones. For alloys such as IN 738, IN 792, U 500, X-750 and the newer alloys such as GTD 111, GTD 111DS, R80DS, and IN 939, which are used in many land-based gas turbines, have been rejuvenated and successfully returned to service according to the previous information of LIBURDI Engineering Company Limited, Canada. In each case, the blades were creep life expired when received for processing and then gave reliable service after rejuvenation.

EXPERIMENTAL MATERIAL AND PROCEDURES

The aim of this research work is to determine the most suitable and practicable repair-condition, which provides the best microstructural characteristics by the rejuvenation method of hot isostatic pressing (HIP) followed by standard heat treatment for long term exposed gas turbine blades, casting nickel base superalloy grade IN-738 (see chemical composition in Table 1), after 70,000-hour service operated by the Electricity Generating Authority of Thailand (EGAT). HIP conditions are illustrated in Table 2, and then the best HIPed specimen was heat treated in standard condition (1125°C / 2 hr. (AC) + 845°C / 24 hr. (AC)). The size of closing voids and/or microcracks was investigated by a scanning electron microscope (SEM).

Table 1 Chemical composition in weight % of IN-738.

Ni	Cr	Co	Mo+W	Al+Ti+Ta+Cb
61	16	8.5	4.4	9.5

Table 2 HIP conditions applied to long term exposed IN-738.

No.	Pressure (MPa)	Temperature (°C)	Time (hr)
1	100	1100	1
2	100	1100	2
3	100	1100	3
4	100	1200	1
5	100	1200	2
6	100	1200	3

RESULTS AND DISCUSSION

The SEM observation of all specimens after long-term service was supposed to confirm the progress of internal voids, as shown in Figures 1-4. The SEM analysis of unetched specimens shows the presence of micro-voids locating both in the matrix and at the carbides, which had been developed during service under long-term stress and temperature. The diameter size and amount of micro-voids depends on the location of the turbine blade. It was found that the zone of the airfoil tips, upper parts of the turbine blade, consist of the more and bigger diameter size of micro-voids. This was because the effect of much higher temperature took place during operation causing a higher rate of diffusion for internal void nucleation and growth.

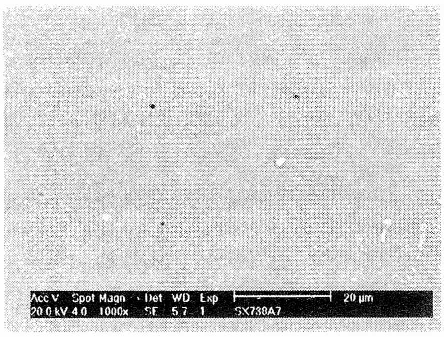

Figure 1 Microvoids locating in matrix.

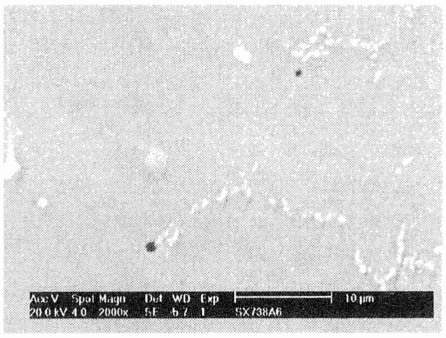

Figure 2 Microvoids locating at carbides.

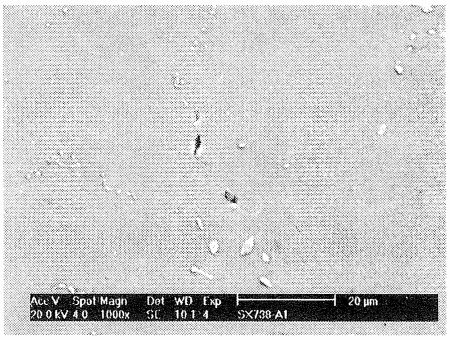

Figure 3 Microcracks locating in matrix.

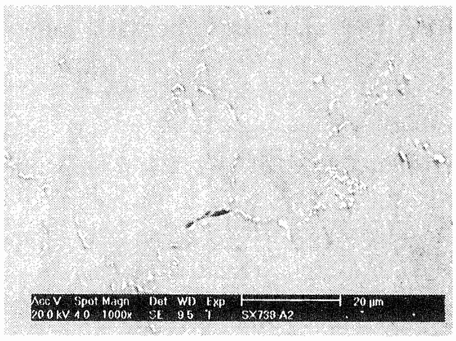

Figure 4 Microcracks locating at carbides.

However, after the HIP process in all testing conditions, it should be noted that the HIP parameters such as temperature and time have a great effect on the efficiency of internal void sintering, see Figure 5. The process temperatures were selected so that the alloy yielded or crept in compression under the action of the applied pressure. The result is elimination of internal voids (porosity) and/or microcracks as well as nearly full densification of the alloy. HIP is able to almost remove internal voids and promote diffusion bonding across the surfaces of the void, which is replaced by continuous material. Higher temperature and longer HIP time show the smaller internal void diameter. As it was already known that a higher temperature and longer time during the HIP process provides the significant beneficial effect in the sintering process. The role of applied temperature and time is to increase the opportunity for diffusion rate and diffusion time to take place across the interface for local yielding and creep, which can increase the real area of contact.

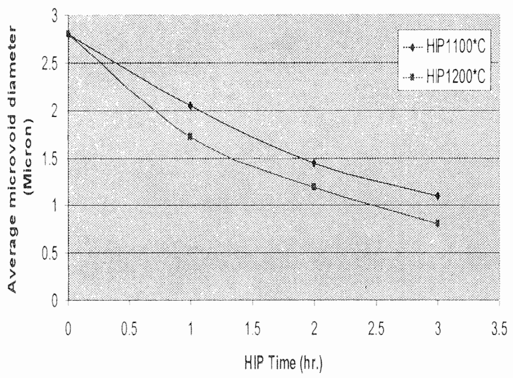

Figure 5 The relationship between internal void diameter and HIP time.

Furthermore, the amount of internal voids (micro-voids) is also dependently decreased by an increase in HIP temperature and time. However, from Figure 5, it should be noted that the internal void closing rate at the earlier stage (0-1 hr.) is a bit faster than that of the middle (1-2 hr.) stage. The last (2-3hr.) stage has a rate of internal void closing a bit slower than that of the middle one. This seems that the efficiency of the HIP process to close the internal void decrease when the period of HIP time increased continuously. Followed by standard heat treatment after HIP programs of No. 3 and No. 6, it was found by SEM investigation that the microstructural homogeneity is clearly increased, Figures 6 and 7. It can be seen by comparing the size and morphology of the gamma prime between the initial state (as-received material after long-term service) and HIPed and then the heat-treated state. All significant features in the microstructure of all HIPed and heat-treated specimens are theoretically supposed to be the desired microstructure for better creep strength (Donachie and Donachie, 2002).

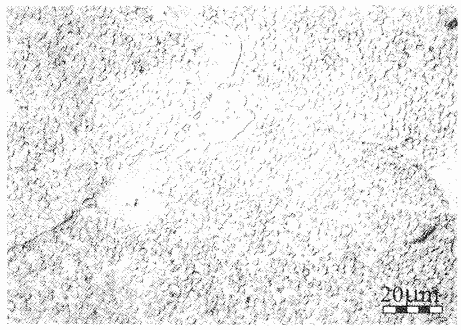

Figure 6 Microstructure before HIP process.

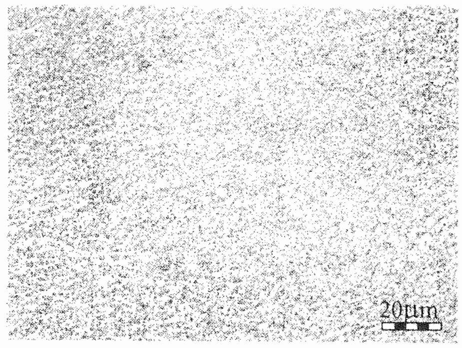

Figure 7 Microstructure after HIP and Heat treatment.

From previous work Donachie and Donachie (2002), which reported that the HIP process can provide the narrowing of the scatterband for some properties in IN-738. While minimum fatigue lives are improved by HIP, minimum rupture lives are not always improved. HIP can be considered as a heat treatment and will dissolve and change γ' in the alloy. The following dissolving and aging heat treatments are required to develop mechanical properties as desired. Furthermore, if the post-HIP solution treatment is not carried out at a temperature above the HIP temperature, the resulting γ' structure may be not adequate to produce optimal strength.

Therefore, this seems that the applied normal standard heat treatment, which consists of solution treatment of 1125°C might not be suitable for proper to the alloy after the HIP process at temperature of 1200°C but this standard heat treatment might only be suitable for the HIP process of 1100°C.

However, according to the previous study Daleo, *et al.* (2002), it reports that a long-term service run IN-738 airfoil that processed through the standard heat treatment, the obtained microstructure could be only partially recovered. This study informed that the most suitable γ' solution temperature for IN-738 alloy ranges from 1175-1190°C. To fully restore the microstructure after service exposure, these alloys are recommended to be dissolve at 1200°C, which is the same as the HIP temperature of the last three programs. As it can be seen that the HIP temperature of 1200°C is already sufficient to completely dissolve γ' particles to the microstructure. Therefore, the standard heat treatment is also possible to be used after the HIP process at temperatures of 1200°C.

Furthermore, according to the another work of authors about re-heat treatment of the alloy published in somewhere of the present Journal, it was earlier found that the low solution temperature (1125°C) of standard heat treatment for long-term service IN-738 turbine blade is adequate to dissolve γ' into the matrix and later providing the uniform dispersed γ' precipitation after the following aging step. In addition, from the result in this present study, it can be also confirmed by Figure 7 that the proper uniform microstructure can be obtained when only the standard heat treatment has been applied after the HIP process at 1200C for the received certain alloy conditions. This can be probably summarized that the level of solution temperature is strongly in dependent with the morphology of precipitated γ' particles of the alloy after long-term service, which the coarser or rafter γ' precipitates (usually occur at very long-term service with high loading and/or very high temperature service conditions) need a higher solution temperature and/or longer solution time. On the other hand, the less coarsening or rafting precipitated γ' particles probably required the lower solutioning temperature and/or shorter solution time as in the standard heat treatment.

CONCLUSIONS

1. Hot isostatic pressing (HIP) offers the possibility of eliminating porosity or voids from shrinkage and creep voids in cast components. No microcrack was observed after the HIP process. HIP is able also to improve the homogeneity of the microstructure, both by dissolution of segregates and by elimination of porosity, as well as the material properties according to previous work (Tien and Caulfield, 1989).

2. After HIP and heat treatment, the microstructure is homogeneous. The dispersion of finer gamma prime precipitates is uniform comparing the microstructure of exposed material. Size and shape of gamma prime precipitates are very similar. Anyway, it should be noted that the heat treatment conditions is just the standard one and might be investigated in the next research about the effect of heat treatment conditions after HIP on the microstructural evolution in the future to study in more details.

3. The higher the HIP temperature and/or the longer of HIP time provide the smaller of closed void or porosity.

FUTURE WORKS

As it can be seen from Figure 5, the final internal void diameter, after HIP at 1200°C for 3 hours, was not zero or very close to zero yet. It means that there are few very small micro voids still found inside the material so it might be recommended that it would be better to continue this HIP research program for longer HIP times such as for 4 and 5 hours and a higher of pressure (such as 120-130 MPa) in the future to completely close any microvoid.

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REFERENCES

Daleo, J. A., Ellison, H. A. and Boone, D.H. 2002. *Eng Gas Turbines Power*, **(July) 124** : 571-579

Donachie, M. J. and Donachie, S. J. 2002. *Superalloys: A Technical Guide*. Metals Park, OH., ASM International.

Sims, C. T. and Boone, D. H. 1995. *Superalloys in Heavy-Duty Gas Turbines V. I.*

Tien, J. K. and Caulfield, T. 1989. *Superalloys, Supercomposites and Superceramics.* New York, Academic Press.

Wangyao, P. et al 2004. *International Symposium on Metallography*, Slovak Rep.

Wangyao, P. et al. 2004. *Acta Metal Slovaca*, pp. 825-828.

Wangyao, P., Joypradit, S., Tuengsook, P., Homkrajai, V., Saengkiettiyut, K., Korath, T. and harnvirojkul, T. 2004. Microstructural repair and rejuvenation in long-term serviced turbine blade, In 738 nickel base superalloy, by HIP process. In: *3rd Thailand Materials Science and Technology Conference*, Bangkok, Thailand : 365-367.

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