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Gamma Prime Coarsening Behavior of Nickel Super alloy Super cast 247A after Prolonged Thermal Exposures

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ABSTRACT : *The commercial nickel-base superalloy Supercast 247A can be used for applications in which high mechanical strength and corrosion resistance at elevated temperatures is required, such as turbine blades and automotive turbocharger rotors. Prolonged isothermal exposure tests were conducted on Supercast 247A alloy to evaluate the variation of gamma prime particle coarsening behavior after different heat treatment conditions. The long-term exposure tests were conducted at 900^0 C to assess gamma prime particle coarsening behavior. Microstructural and Mechanical studies were performed on isothermally aged samples to characterize gamma prime coarsening as a function of aging time and temperature. The gamma prime particles appeared to be more coarsening into round shape or agglomerated between them compared to the initial ones of each heat treatment. The degree of coarsening, as evidenced by gamma prime particle size, increased with increasing heating time and temperature. In most cases, the amount of secondary or very fine gamma prime precipitates decreased with increasing heating temperature and finally disappeared. It was found that the lower solution temperature provided the highest rate of γ' coarsening at both elevated temperatures. In contrast, the higher solution temperature kept the slow rate of γ' coarsening resulting in lower average γ' particle size.*

Keywords – *Ni-base superalloy, Supercast 247A, Gamma Prime Coarsening, Aging treat. & Microstructure*

I. INTRODUCTION

The Nickel base superalloys used in modern gas turbines are continuously being developed to increase thrust, operating efficiency and durability. For many years, Ni base superalloys have been used in gas turbines as blades at high temperature because of its excellent high temperature mechanical properties [1,5]. Generally, the Ni-base superalloys with complex and multi-phase microstructures are stable at high temperatures and this characteristic is the main reason for using them in critical and severe service conditions [6-9]. The strengthening of nickel-based superalloys is mainly obtained by the coherent precipitation of a large amount of Ni3 (Al, Ti) type γ' phase in a nickel-based γ matrix. The morphology of the γ' precipitates in these alloys has been well documented and a large variety of the γ' precipitate shapes have been observed (spheres, cubes, aligned cubes, plates, short plates, a doublet of short plates, an octet of cubes, large plates, rafts etc.) [10-13]. The size, volume fraction and distribution of gamma prime phase are vital to control the creep strength at high intermediate stresses. The proper reheat-treated microstructure can provide their phase stability, adequate high strength and good ductility even after long-term thermal exposure. The mechanical property behaviors of superalloys are very strongly related to the alloy microstructures [2-6]. The superalloy microstructures continually change with time at the elevated temperatures. In the new, heat treated alloy, the gamma prime particles are arranged in a structure, which results in an optimum balance of tensile, fatigue, and creep properties [7-10]. It is generally known that mechanical properties are related to the microstructures. Therefore, many previous research works [3-11] have been carried out to investigate the relationships of microstructure and mechanical properties. However, the use of these expensive materials requires a repair process providing the re-establishment of the initial properties and the original microstructure of the long term used or damaged parts for the economic reason. The heat-treatment processes for nickel-based superalloys continue to change in order to optimize numerous mechanical and physical properties [5-9]. This allows making the selection of heat treatment parameters increasingly challenging.The present research work is directed towards determining the effect of heat treatments (solution treatment and aging treatments) in a Supercast 247A nickel-base superalloy, equivalent to CM 247LC developed by Mishra Dhatu Nigam Limited, Hyderabad, India, with R&D inputs from the Defense Metallurgical Research Laboratory, Hyderabad, India. In this study, Prolonged isothermal exposure tests were conducted on Supercast 247A alloy to evaluate the variation of gamma prime particle coarsening behavior after different heat treatment conditions.

II. EXPERIMENTAL WORK

The alloy used in here was originally melted by vacuum induction melting (VIM) at the Mishra Dhatu Nigam Limited, Hyderabad. The alloy was remelted in an alumina crucible in a VIM furnace and poured at

1753~1793K into a ceramic shell mold with a CoO face coat, at the Defense Metallurgical Research Laboratory, Hyderabad. The ceramic shell mold was maintained at 1393K, Table 1 presents the nominal composition of the alloy. After casting all test bars were subjected to radiography, for ensuring the internal soundness. The specimens were then heat treated in a vacuum. The standard heat treatment process consists of solution treatments at 1503K and 1533K for 2 hours followed by argon gas fan quenching (GFQ), and subsequently aging treatments at 1353K/4 hours and 1143K/ 20 hours followed by furnace cooling (F.C) (called as condition SA). After Solution Treatment and Aging, samples were exposed to a temperature of 900°C for various time periods of 25 hours (SA1), 50 hours (SA2), 75 hours (SA3), 100 hours (SA4) and 125 hours (SA5). All sectioned samples after each aging were ground and polished using standard metallographic techniques and were subsequently etched in marble etchant. The microstructures was evaluated by optical microscopy (OM) and scanning electron microscopy (SEM) of each condition. Tensile tests were performed at room temperature (RT) using an Instron 5500R universal testing machine at a crosshead speed of 1 mm min^{-1} (i.e., At an initial strain rate of ~$5*10^{-4}$ s^{-1}) using rounded specimens of gauge length 25 mm and width 3.88 mm. The axial strain was monitored with the help of an extensometer of 25 mm gauge length span. The Vickers hardness was measured by Buehler Vickers's hardness testing machine under a load of 30 kilograms.

Table 1 Nominal composition of various elements (in mass %) of Supercast 247A

Element	Ni	C	Cr	Co	Mo	Ta	Ti	W	Al	Hf	B	Zr
Wt (%)	Balnce	0.074	8.2	9.30	0.505	3.185	0.81	9.5	5.6	1.51	0.015	0.014

III. RESULTS AND DISCUSSION

1. Microstructural Properties

The microstructures shown in Fig. 1(a)-(b) are for Supercast 247A superalloy as cast condition. The structure consists of ordered γ' intermetallic phase dispersed in a γ matrix. The primary γ-γ' eutectic phase is mainly at the grain boundaries, with only a small portion within the grains and MC type carbide has an irregular shape. Generally bimodal, spheroidal and cuboidal shape, and duplex precipitates, fine and coarse γ' phase are found in them as cast microstructure [14-16]. In the dendritic region, there are fine γ' precipitates while in the inter dendritic region, coarse size γ' precipitates exist, as it has been also observed by [17]. Aging at high temperature resulted in drastically coarser gamma prime particles as compared to the initially received specimens, see Fig.2 (a)-(e). The gamma prime particles greatly coarsened more into a round spherical shape than those in each initially heat treated specimens. In the alloy, the degree of coarsening, as determined by gamma prime particle size, increased with increasing aging time. At the aging temperature, the size of gamma prime particles increased, and the area fraction of secondary gamma prime particles decreased with increasing aging time. During long-term aging secondary gamma prime particles would dissolve into the matrix and then diffused to agglomerate with the primary gamma prime particles. Considering the coarsening behavior of gamma prime particles at 900ºC (Fig. 2 and 3), it was found that the microstructures under solution plus aging treatment condition i.e., SA were the most stable ones due to the slowest coarsening rate of gamma prime particles. However, when considering Fig. 2, it could be seen that the area fraction of total gamma prime particles of the specimen under heat treatment condition SA1 was more constant compared to condition SA5. Therefore, the heat treated condition SA (solution plus aging treatments) could be assumed to provide the most stable microstructure under long-term exposure at 900ºC compared to the others.

2. Mechanical Properties

The mechanical properties of conventional cast aged nickel-base superalloys are the principal functions of the content and morphology of the γ' phase, volume fraction and carbide distribution. Table 4 and Fig. 3 presents the tensile and hardness properties of Supercast 247A superalloy with various thermal exposure conditions as well as γ' particle sizes. As seen from the test results it is observed that the sample tested for SA condition has resulted in higher yield strength and tensile strength. The sample tested for SA1 condition slightly inferior in properties to that of solution plus aging heat treatment condition and in as cast condition has given the lowest yield strength and tensile strength. Table 2 shows the properties obtained on the samples tested in different conditions and the corresponding γ′ particle size measured in the particular condition. In this research, the fine grain Supercast 247A superalloy exhibits higher ultimate tensile strength, yield strength and lower elongation over those values of coarse grain Supercast 247A superalloy at room temperature. Further, the tensile properties are well in compliance with the formula derived for precipitation strengthened Ni-base superalloys, which says: $\tau = Gb/\lambda$, Where τ is the stress to shear the particle, λ is the inter particle spacing, G is the shear modulus and b is the burger vector.

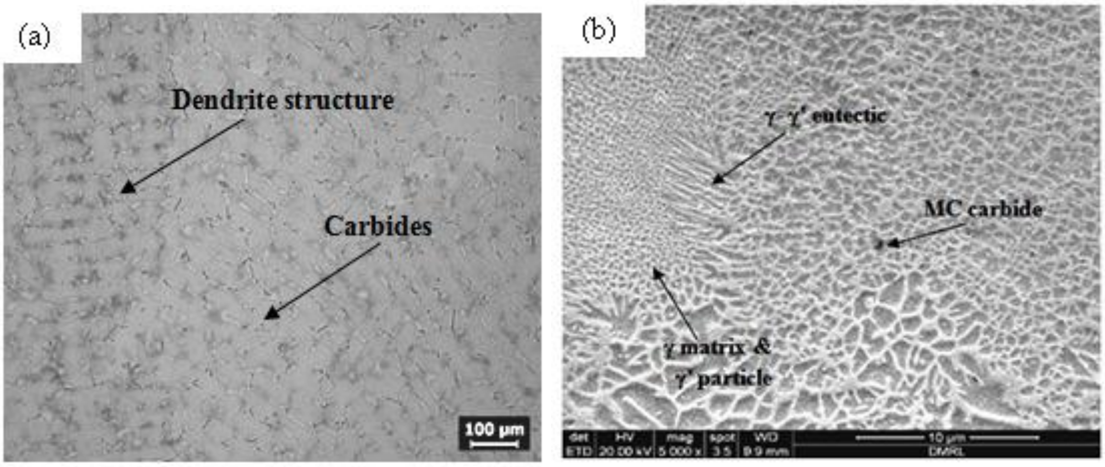

Fig. 1 (a) Optical micrograph (b) SEM showing the as cast microstructure of Supercast 247A Superalloy

Table 2 : Mechanical Properties of Supercast 247A in as-cast and three different Thermal Exposure Conditions

Condition	γ' Size (µm)	Volume Fraction (%)	Yield Strength (Mpa)	UTS (Mpa)	Vickers Hardness
SA	0.74	43.72	860	995	385
SA1	0.89	37.84	847	972	396
SA2	0.75	46.38	825	960	385
SA3	0.93	56.34	764	970	370
SA4	0.86	47.91	762	965	366
SA5	1.10	37.25	725	957	366

The Fig. 3 (b) and 3 (d) shows the comparison of hardness vs tensile strength and effect of gamma prime particle size on the hardness property of specimens under each heat treatment. It is clearly seen that the size of very fine gamma prime particles has no significant effect on hardness properties. As seen from Fig. 3 that the hardness increases with the volume fraction of very fine gamma prime particles and total volume fraction of gamma prime particles of heat-treated specimens before final aging. However, the hardness is more related to the volume fraction of very fine gamma prime particles rather than to the latter. Furthermore, the increase of volume fraction of more precipitated very fine gamma prime particles is also reasonably linked to the decrease of volume fraction of precipitated coarse gamma prime particles. However, in contrast, the size reduction of coarse gamma prime particles (resulting in an increase of volume fraction of very fine gamma prime precipitation) is probably related to the increase of hardness.

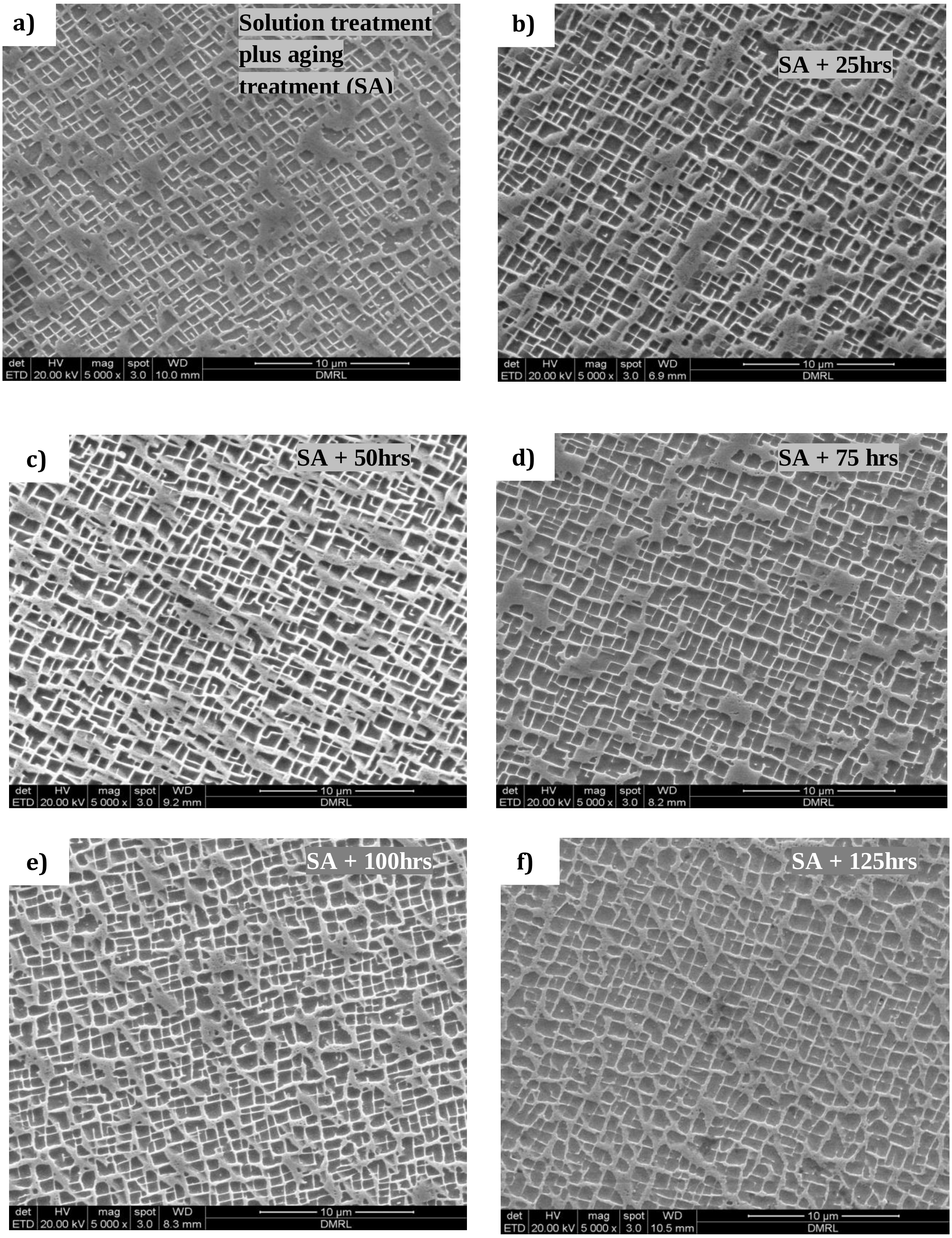

Fig.2. SEM showing the gamma prime behavior of a) SA b) SA1 c) SA2 d) SA3 e) SA4 f) SA5 conditions respectively

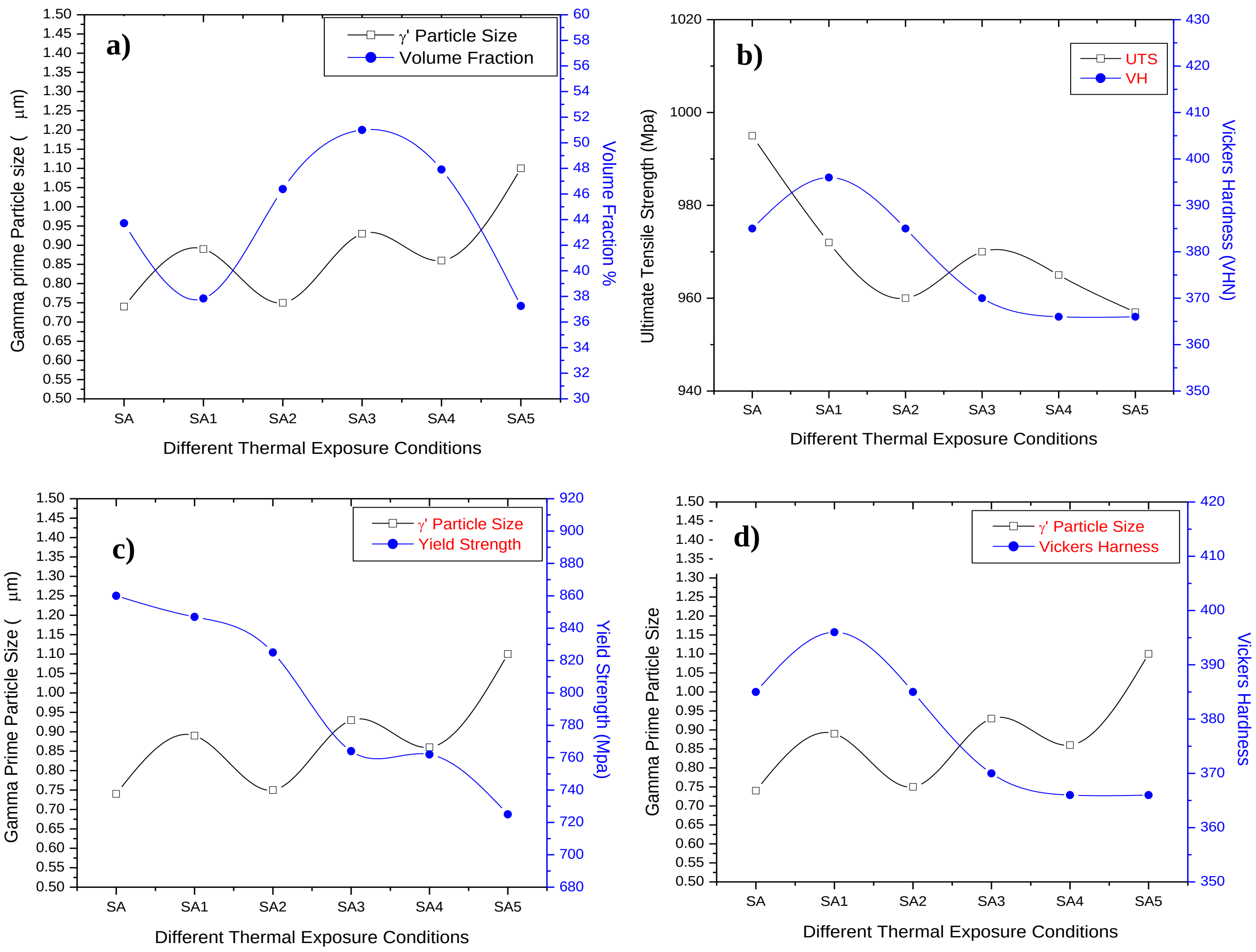

Fig. 3 : Realtionship between Heating time with (a) Gamma prime particle size and Volume fraction (b) Ultimate Tensile Strength and Vickers Hardness (c) Gamma Particle Size and Yield Strength and (d) Gamma Particle Size and Vickers Hardness

IV. CONCLUSION

1. A general Microstructural examination by optical and scanning electron microscopy of Nickel base cast superalloy Supercast 247 A, in different thermal exposure conditions has helped in understanding the physical metallurgy and coarsing and deformation behavior of the above advanced superalloy with an extremely narrow range of composition limits
2. After various heat treatment conditions, the microstructures seem to be the optimized microstructures for mechanical properties at elevated temperatures due to its maximum volume fraction.
3. The higher temperature of solution treatment provided the higher coarse γ' particles in smaller size. However, the increase of inserted primary aging temperature resulted in an increase of gamma prime particle size.
4. Tensile tests and hardness results reveal that the fine grain size i.e, SA condition sample has a higher yield strength, UTS and lower elongation than those of as cast and other heat treatment conditions.

REFERENCES

[1] J.S. Houa, J.T. Guoa, L.Z. Zhoua, C. Yuana, H.Q. Ye, *Journal of Materials Science and Engineering*, A 374, 2004, 327.
[2] B. G. Choi, I. S. Kim, D. H. Kim, C., *Journal of Materials Science and Engineering*, A 478, 2008, 329.
[3] S. A. Sajjadi, S. Nategh, R. I. L. Guthrie, *Journal of Materials Science and Engineering*, A 325, 2002, 484.
[4] C.T. Liua, J. Ma, X.F. Sun, *Journal of Alloys and Compounds* ,491, ,2010, 522.
[5] S.A. Sajjadi, S. Nategh, *Journal of Materials Science and Engineering*, A 307, 2001, 158.
[6] F. Long, Y.S. Yoo, C.Y. Jo, S.M. Seo, Y.S. Song, T. Jin, Z.Q. Hu, *Journal of Materials Science and Engineering*, A 527, 2009, 361.
[7] S.A. SAjjadi, S.M. Zebarjad, R. I. L. Guthrie, M. Isac, *Materials Processing Technology*, 175, 2006, 376.
[8] M. Pouranvari, A. Ekrami, A.H. Kokabi, *Alloys and Compounds*, 461, 2008, 641.
[9] A. Jacques, F. Diologent, P. Caron, P. Bastie, *Materials Science and Engineering*, A 483– 484, 2008, 568.
[10] A.D. Sequeira, H.A. Calderon, G. Kostorz, *Scripta Metallurgica Materialia*, 30, 1994, 75.
[11] T. Grosdidier, A. Hazotte, A. Simon, *Scripta Metallurgica Materialia*, 30, 1994, 1257.
[12] S. Kraft, I. Altenberger, H. Mughrabi, *Scripta Metallurgica Materialia*, 32, 1995, 411.
[13] Y. Y. Qiu, Acta Materialia 44 (1996) 4969. [14] S.H. Mousavi Anijdan, A. Bahrami, *Materials Science and Engineering*, A 396, 2005, 138.
[14] G.E. Fuchs, Mater. Sci. Engineering, A 300, 2001,52.
[15] G.E. Fuchs, *J. Mater. Eng. Perform*, 11, 2002, 1925.
[16] [M.T. Kim, S.Y. Chang, J.B. Won, *Material science and Engineering*, A 441, 2006, 126.