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Effect of Temperature Dropping During Solution Treatment in Rejuvenation Heat Treatment on Final Microstructures of Udimet 520

Kritsayanee SAELOR* and Panyawat WANGYAO

Innovative Metals Research Unit,Metallurgical Engineering Department,
Engineering Faculty, Chulalongkorn University, Bangkok, Thailand

Abstract

Udimet 520 is a low precipitation hardened nickel-based superalloy, which is made to be turbine blades at high temperature.(1) After long-term service, the microstructure of the turbine blades could be degraded, then the mechanical properties are worse than the new ones. The rejuvenation heat treatment of degraded turbine blades, which are made of cast Udimet 520, is following by solution treatment at 1,121°C / 4 hours and then double aging processes, which include primary aging at 843°C / 24 hours and secondary aging at 760°C / 16 hours, respectively.(1-2) However, in practical reheat treatment processes, the temperature during solution treatment can be dropped by error or malfunction of heating furnace because the furnace has to be operated at very high temperature for long time. Simulating this effect, the droppings of temperature during solution treatment are chosen and performed for 3 levels; 840°C, 800°C and 760°C, which could happen in practical working then heated up again immediately to solution temperature level. The maximum number of temperature dropping during the single solution treatment is up to 3 times. Received results show that the effect of temperature dropping during solution treatment has influenced on the final rejuvenated microstructures slightly due to the alloy is low precipitation behavior.

Keywords : Nickel base superalloy, Rejuvenation heat treatment, Udimet 520, Solution treatment, Microstructure, Gamma prime

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Introduction

An important property of materials for being used as turbine blade is strength at high temperature. Nickel-based superalloy; are used as required materials for production of turbine blades because of its properties such as good strength and creep resistance, etc.(3-6) Udimet 520 is one of nickel-based superalloys, which has been for turbine blade material since 1960s and is still used at Electricity Generating Authority of Thailand. Due to the prize of turbine blade and its manufacturing process are very expensive, rejuvenation heat treatment is normally applied to renew or restore nearly new microstructure for service lifetime extension.(7-9)

The rejuvenation heat treatment of Udimet 520 usually consists of three steps : solution treatment, carbide stabilization and precipitation aging. The solution step is very important process to control the final microstructure, which influences on mechanical properties.(10-11) Thus this work has an aim to study the effect of temperature dropping conditions during solution treatment in rejuvenation heat treatment on final microstructures of Udimet 520**.**

Materials and Experimental Procedures

The chemical composition of cast nickel base superalloy, grade Udimet 520 is shown in Table1.

Table 1. The chemical composition of nickel-based superalloy, grade Udimet 520.

Chemical composition (wt. %)											
Ni	Cr	Co	Mo	Ti	Al	W	Fe	Si	Mn	B	C
Bal	18.39	9.53	5.69	2.77	2.06	0.84	0.12	0.03	0.02	0.004	0.002

Corresponding author E-mail : kritsayanee@gmail.com , panyawat@hotmail.com

The specimens were cut in the size of about 1 cm^3, which prepared for rejuvenation heat treatment for various 16 conditions, as shown the reheating schemes in Figures 1-6. The rejuvenation heat treatments for this study, which are there 3 steps; the first step is solution treatment (as follows: schemes 1-6). Then all reheat treated specimens after these schemes 1-6 will be continuously performed with the second step is carbide stabilization and primary aging (at 843°C/24 hour) and the last one is secondary aging (at 760°C/16 hours.).

Scheme 1: The solution treatment condition of figure 1 as follows.
Standard condition: Solution Treatment at 1,121°C for 4 hours after that air cooling

Scheme 2: The solution treatment condition of figure 2 as follows.
A1-3 condition: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 840°C + Reheating to 1,121°C for 3 hours after that air cooling
B1-3 condition: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 800°C + Heating up to 1,121°C for 3 hours after that air cooling
C1-3 condition: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 760°C + Heating up to 1,121°C for 3 hours after that air cooling

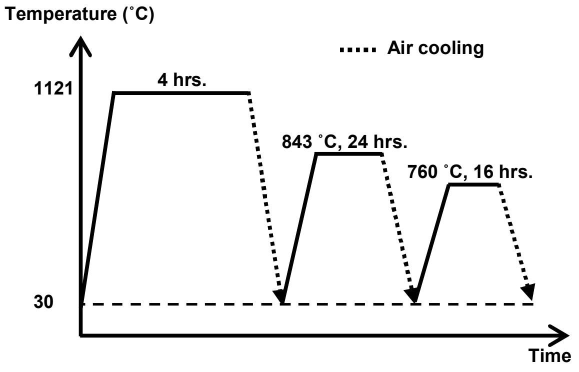

Figure 1. Rejuvenation heat treatment diagram with standard condition

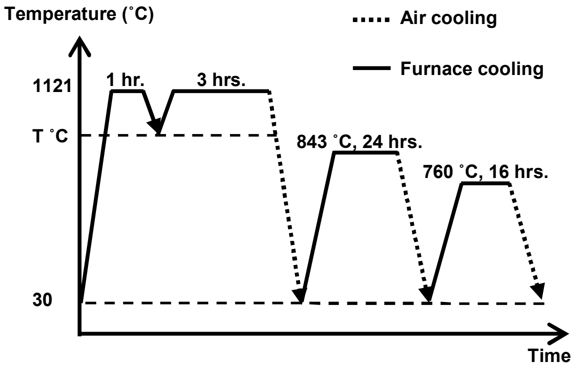

Figure 2. Rejuvenation heat treatment diagram with A1-3, B1-3 and C1-3conditions

Scheme 3: The solution treatment condition of figure 3 as follows.
Condition A2-2: Solution Treatment at 1,121°C for 2 hours + Temperature dropping to 840°C + Heating up to 1,121°C for 2 hours after that air cooling
Condition B2-2: Solution Treatment at 1,121°C for 2 hours + Temperature dropping to 800°C + Heating up to 1,121°C for 2 hours after that air cooling
Condition C2-2: Solution Treatment at 1,121°C for 2 hours + Temperature dropping to 760°C + Heating up to 1,121°C for 2 hours after that air cooling

Scheme 4: The solution treatment condition of figure 4 as follows.
Condition A3-1: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 840°C + Heating up to 1,121°C for 3 hours after that air cooling
Condition B3-1: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 800°C + Heating up to 1,121°C for 3 hours after that air cooling
Condition C3-1: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 760°C + Heating up to 1,121°C for 3 hours after that air cooling

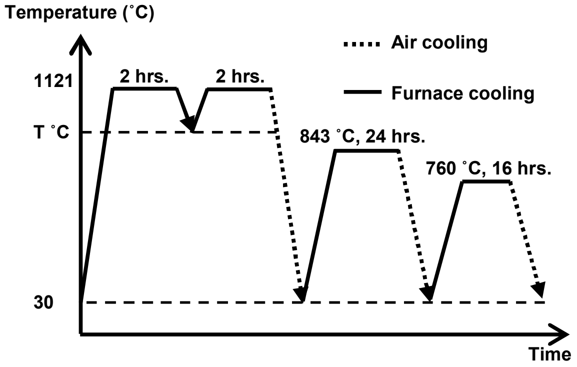

Figure 3. Rejuvenation heat treatment diagram with A2-2, B2-2 and C2-2conditions

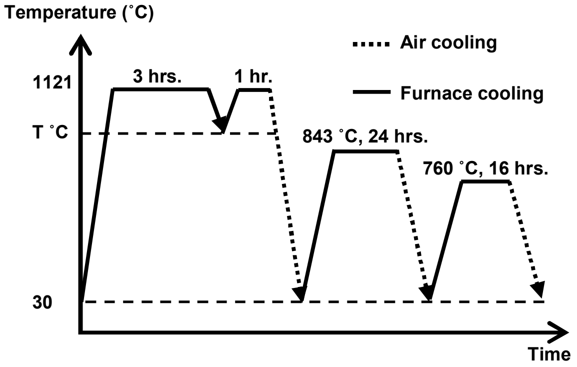

Figure 4. Rejuvenation heat treatment diagram with A3-1, B3-1 and C3-1conditions

Scheme 5: The solution treatment condition of figure 5 as follows.

Condition A1-2-1: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 840°C + Heating up to 1,121°C for 2 hours + Temperature dropping to 840°C + Heating up to 1,121°C for 1 hour after that air cooling

Condition B1-2-1: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 800°C + Heating up to 1,121°C for 2 hours + Temperature dropping to 800°C + Heating up to 1,121°C for 1 hour after that air cooling

Condition C1-2-1: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 760°C + Heating up to 1,121°C for 2 hours + Temperature dropping to 760°C + Heating up to 1,121°C for 1 hour after that air cooling

Scheme 6: The solution treatment condition of figure 6 as follows.

Condition A1-1-1-1: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 840°C + Heating up to 1,121°C for 1 hour + Temperature dropping to 840°C + Heating up to 1,121°C for 1 hour + Temperature dropping to 840°C + Heating up to 1,121°C for 1 hour after that air cooling

Condition B1-1-1-1: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 800°C + Heating up to 1,121°C for 1 hour + Temperature dropping to 800°C + Heating up to 1,121°C for 1 hour + Temperature dropping to 800°C + Heating up to 1,121°C for 1 hour after that air cooling

Condition C1-1-1-1: Solution Treatment at 1,121°C for 1 hour + Temperature dropping to 760°C + Heating up to 1,121°C for 1 hour + Temperature dropping to 760°C + Heating up to 1,121°C for 1 hour + Temperature dropping to 760°C + Heating up to 1,121°C for 1 hour after that air cooling

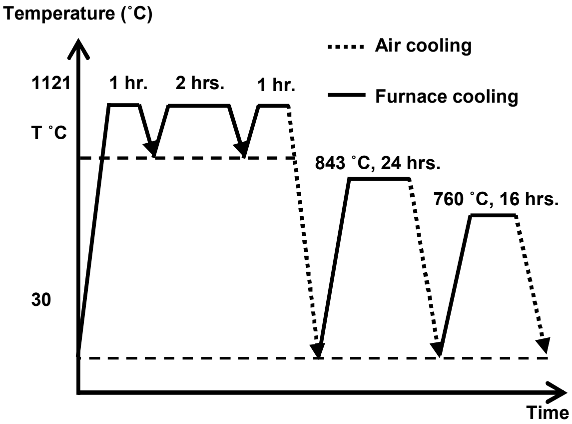

Figure 5. Rejuvenation heat treatment diagram with A1-2-1, B1-2-1 and C1-2-1conditions

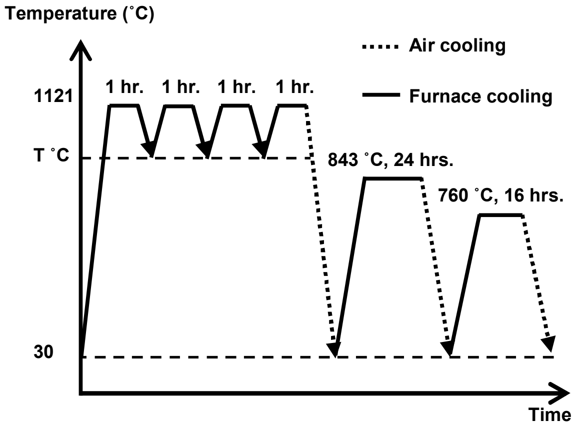

Figure 6. Rejuvenation heat treatment diagram with A1-1-1-1, B1-1-1-1and C1-1-1-1 conditions

All specimens were polished using standard metallographic techniques and were subsequently etched in marble etchant, which has the following chemical composition: 10 g $CuSO_4$, 50 ml HCl, and 50 ml H_2O. The microstructures of heat treatment samples were studied by scanning electron microscope and image analyzer.

Results and Discussion

1. Microstructure of as-receive specimens

Figure 7 shows microstructure of superalloy Udimet 520 after 50,000 hours service, it can be seen that the gamma prime particles are coalesced. This kind of gamma prime coarsening with lower coherence with the gamma matrix could result in less the mechanical properties according to many previous works

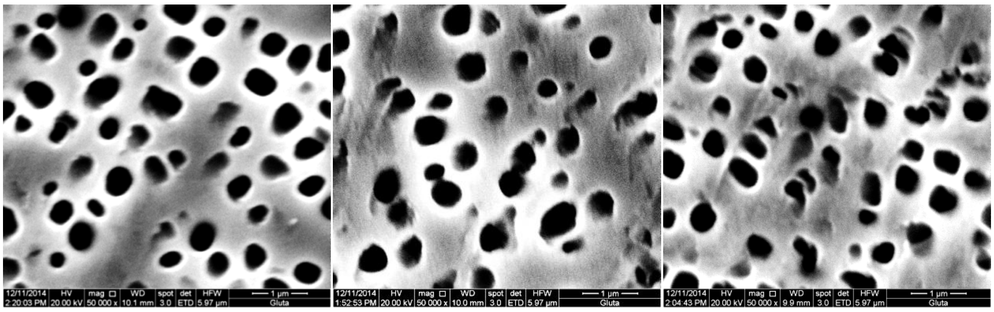

Figure 7. Microstructures of as-received specimens.

2. Microstructures of standard heat treatment condition

The microstructures of specimens after standard rejuvenation heat treatment are shown in Figure 8. They contain a single size of gamma prime particles, which is about 0.0029-0.0039 μm^2. It could be indicated that the standard heat treatment can completely dissolve the coalescent gamma prime particles to the gamma matrix.

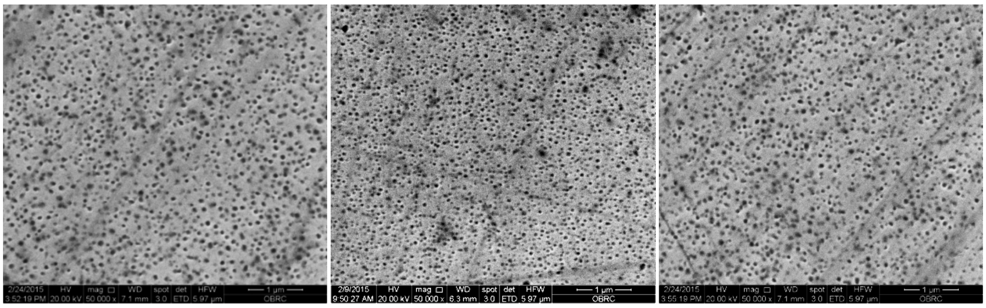

Figure 8. Microstructures of specimens after the standard rejuvenation heat treatment.

3. Microstructures of A1-3, B1-3 and C1-3 reheat treatment conditions

The microstructures of specimens after rejuvenated heat treatment A1-3, B1-3 and C1-3 conditions are shown in Figure 9 a) - c), respectively. These reheat treatment conditions with temperature dropping still can dissolve the coalescent gamma prime particles into the matrix completely even though there is a dropping temperature after first hour of solution treatment. The later three hours solutioning was enough for dissolving coarsen gamma prime particles into the gamma matrix.

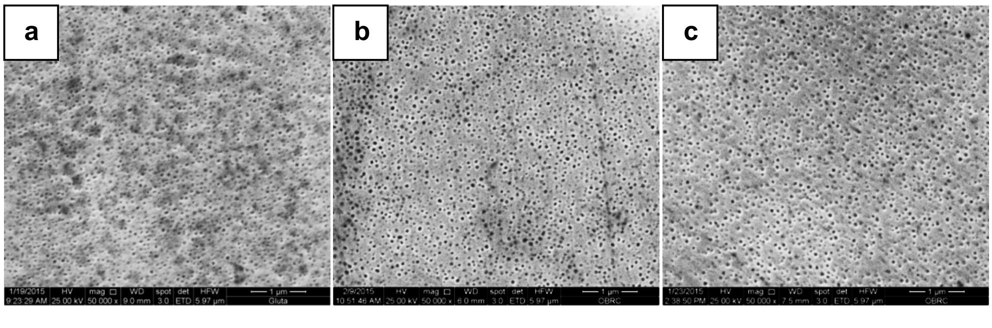

Figure 9. Microstructures of specimens after heat treatment a) A1-3, b) B1-3 and C1-3 conditions.

4. Microstructures of A2-2, B2-2 and C2-2 reheat treatment conditions

Figures 10 a) - c) show the microstructures of specimens after rejuvenated heat treatment of A2-2, B2-2 and C2-2 conditions. From this figures, the gamma prime particles after these rejuvenated heat treatment conditions are almost similar in size and shape of gamma prime. Comparing to those of specimens of rejuvenated heat treatment of A1-3, B1-3 and C1-3 conditions (Figure 9) but the gamma prime particles are slightly bigger. Each condition in Figure 10, there is only single size of gamma prime particles so these rejuvenated heat treatment conditions can also dissolve the coarse gamma prime particles completely.

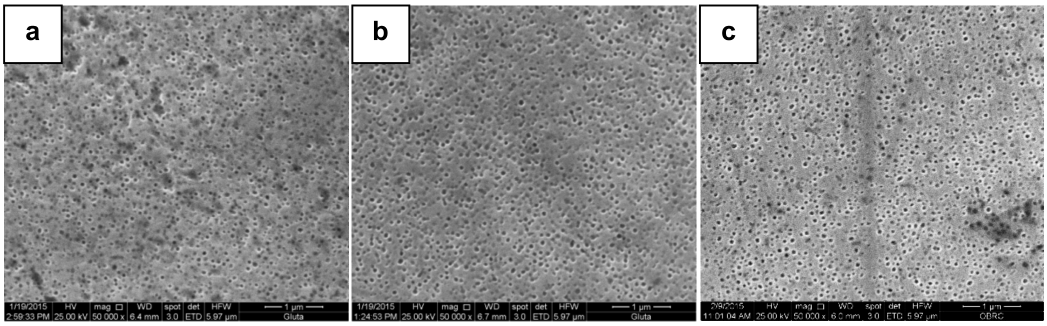

Figure 10. Microstructures of specimens after heat treatment a) A2-2, b) B2-2 and C2-2 conditions.

5. Microstructures of A3-1, B3-1 and C3-1 reheat treatment conditions

The microstructures in Figure 11 with rejuvenated heat treatment of A3-1, B3-1 and C3-1 conditions are shown in Figures 11 a) - c), respectively. At the same temperature dropping, the gamma prime phase of specimens after these rejuvenated heat treatment conditions has slightly bigger size and higher amount of gamma prime particles than those of specimens after A1-3, B1-3 and C1-3 reheat treatment conditions. However, these rejuvenated heat treatment conditions can also dissolve the coalescent gamma prime particles into the austenite matrix completely.

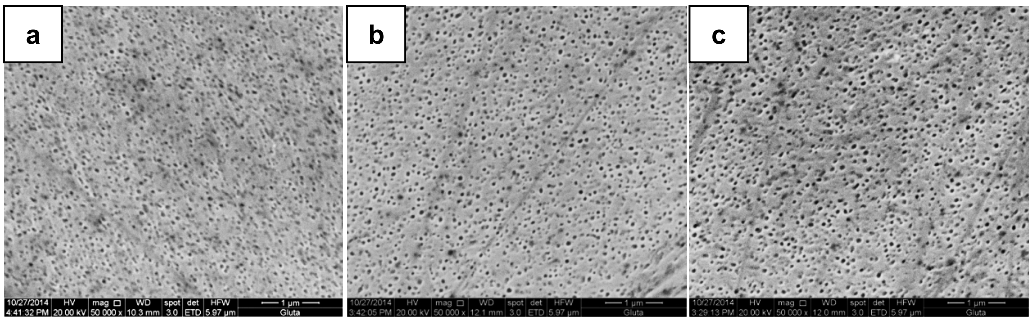

Figure 11. Microstructures of specimens after heat treatment a) A3-1, b) B3-1 and C3-1 conditions.

6. Microstructures of A1-2-1, B1-2-1 and C1-2-1 reheat treatment conditions

The microstructures of specimens after rejuvenated heat treatment of A1-2-1, B1-2-1 and C1-2-1 conditions are shown in Figures 12 a) - c), respectively. These conditions also can dissolve the coalescent gamma prime particles into the matrix completely even though there are twice temperature droppings between the solution treatment process. The later hour of the solution treatment process is enough for coarsen gamma prime particles and/or re-precipitating gamma prime particles, which precipitate between temperature dropping into the matrix dissolution.

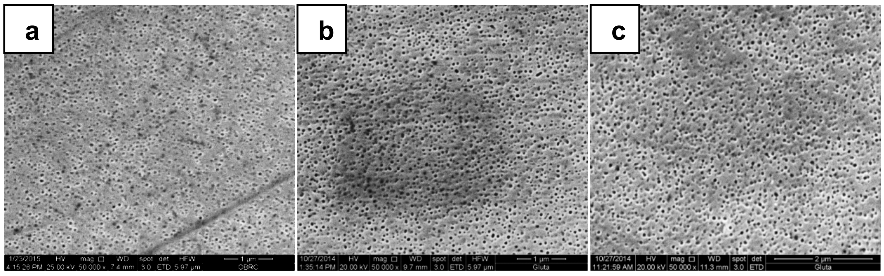

Figure 12. Microstructures of specimens after heat treatment a) A1-2-1, b) B1-2-1 and C1-2-1 conditions.

7. Microstructures of A1-1-1-1, B1-1-1-1 and C1-1-1-1 reheat treatment conditions

The rejuvenation heat treatment A1-1-1, B1-1-1-1 and C1-1-1-1 conditions, there are the temperature droppings 3 times during a solution treatment process. From the microstructures of Figures 13 a) - c), it can be clearly seen that the latest solutioning could also dissolve the coalescent gamma prime particles into the matrix completely. The gamma prime particles are nearly one size.

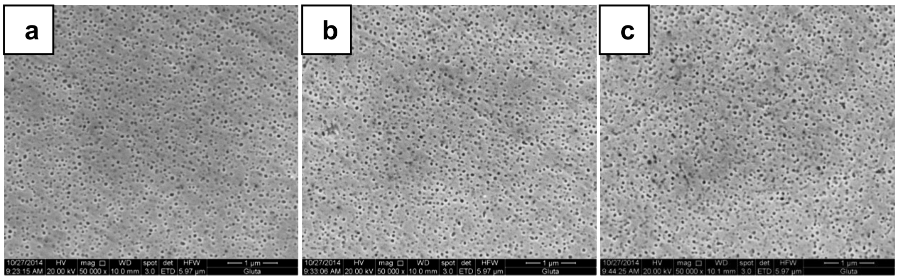

Figure 13. Microstructures of specimens after heat treatment a) A1-1-1, b) B1-1-1-1 and C1-1-1-1 conditions.

8. Image analysis of rejuvenatedmicrostructures

The effects of degree and times of temperature droppings on average gamma prime particle size and area fraction of gamma prime particles are shown in Figures 14 and 15, respectively.The microstructures of all rejuvenation heat treatment conditions are quite similar. This is due to that Udimet 520 is a low precipitation hardened superalloy, which solutioning can easily dissolve the coalescent gamma prime particles and/or re-precipitating gamma prime particles into the austenite gamma matrix for short period of time (an hour) completely. The degree of temperature dropping provides slight effects on gamma prime particle size and area fraction of gamma prime. The higher degree and more times of temperature dropping resulted in the average area of gamma prime particle and average area fraction of gamma prime particles increase slightly.

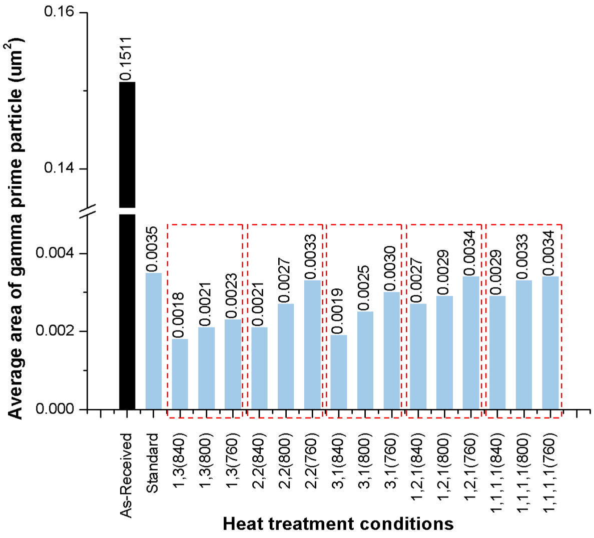

Figure 14. Average area of gamma prime particle of specimens after heat treatment conditions.

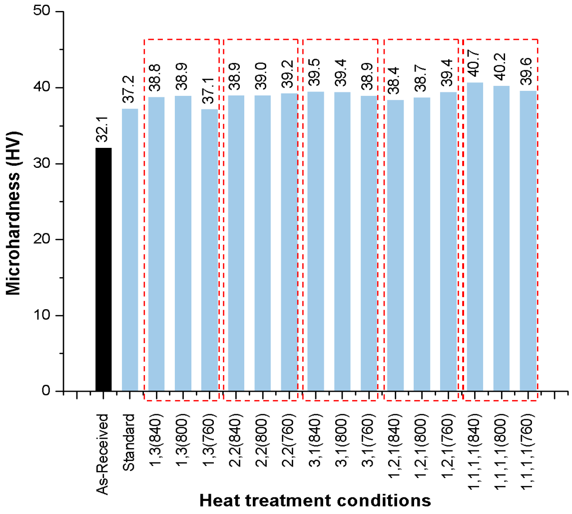

Figure 15. Average area fraction of gamma prime ofspecimens afterheat treatment conditions.

9. Microhardness results

Figure 16 shows the results of microhardness (HV) of all specimens after rejuvenated heat treatment conditions, it was found that the hardness values are in the range of 37.2-39.6 HV, which are very similar to each other. From the results of microhardness show that all rejuvenated heat treatment conditions could dissolve the coarsen gamma prime particles and/or re-precipitating gamma prime particles into the austenite matrix completely and provide the uniformity of fine gamma prime precipitation through out the gamma matrix in similar morphology.

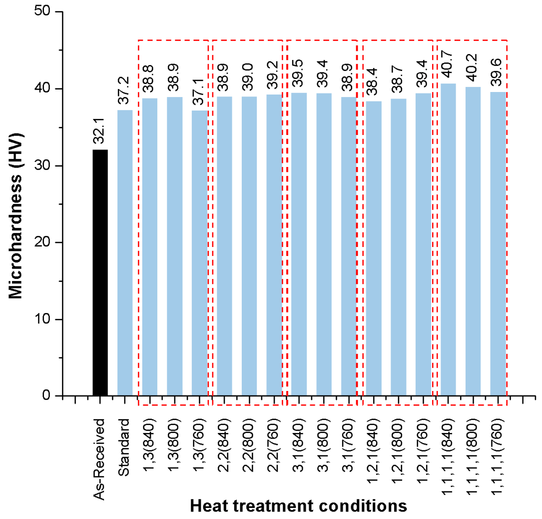

Figure 16. Average microhardness of specimens after heat treatment conditions.

Conclusions

1. The degree of temperature droppings influence on gamma prime particle size and area fraction of gamma prime. The higher degree and more times of temperature dropping resulted in slightly increasing of the average area of gamma prime particle and average area fraction of gamma prime particles.

2. Although there are some temperature droppings between the solution treatment process, all these conditions still could dissolve the coalescent gamma prime particles and/or re-precipitating gamma prime particles into the matrix completely.

3. The results of microhardness could also confirm that all these rejuvenation heat treatment conditions could dissolve the coalescent gamma prime particles and/or re-precipitating gamma prime particles into the matrix completely.

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