Effect of Precipitation Aging Temperatures on Rejuvenation Heat Treated microstructures, Hardness and γ' Phase Stability in Udimet-500

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Abstract

This research has studied the effect of precipitation aging temperatures on size and area density ofγ' – particles of the reheat treated microstructures incast nickel basesuperalloy, grade Udimet-500. All specimens were performed the same solutioning treatment at temperature of 1,150°C for 4 hours following with various precipitation aging temperatures of 760, 780, 800 and 820°C for 16 hours. Furthermore, these reheat treated specimens were also performed long-term heating at temperatures of 900°C and 1000°C for 200 hours to evaluate γ'-phase stability. Finally, hardness measurements were also carried out. Form all obtained results, it was found that the standard precipitation aging temperature of 760°C for 16 hours provided the most phase stability after long-term tests as well as the maximum hardness.

Introduction

Udimet-500 is one of cast nickel based superalloysused gas turbine blade material in gas turbine enginesfor electricity generating. After long-term service, themicrostructure of the alloy, which consists of gamma (γ), gamma prime(γ') and/or carbides would be detrimentallydegraded leading to much lower mechanical propertiesat high temperatures. However, these kinds of γ' precipitated strengthening materials could be microstructallyrestored by rejuvenation heat treatment, which basically consists of solutioning treatment and precipitation aging to provide the microstructural refurbishment as same as the news ones.[1-4]

The research will study the effect of precipitation aging temperatures in final microstructures in terms of size and area density of γ'-particles as well as the effect of these obtained microstructural characteristics on hardness behavior. Furthermore, the long-term heating at high temperatures were also performed to evaluate the γ'-phase stability at long-term exposures in Udimet-500.

Materials and Experimental Procedures

The investigated material is cast nickel-based superalloy, grade Udimet-500, a turbine blade material in gas turbine engines, which was used at high temperatures for 50,000 hours by Electricity Generating Authority of Thailand (EGAT). The chemical composition of the alloy shown in Table 1.

Table 1. The chemical composition of cast nickel-base superalloy, grade Udimet-500

Elements	Ni	Cr	Co	Ti	W	Al	Ta	Mo	Fe	C	B	Zr
Weight Percent (%wt.)	Bal.	18	17	3	-	3	-	4	2	0.1	-	-

The alloy was performed with various reheat treatment processes as following:

1. Solution treatment at temperature of 1,150°C for 4 hours then following with air cooling.
2. Precipitation aging at temperatures of 760, 780, 800 and 820°C for 16 hours then following with air cooling.

Then these received specimens after various reheat treatment conditions were prepared with cutting, grinding, polishing and etching for metallography analysis by Scanning Electron Microscopy (SEM). Furthermore, to investigate and evaluate the γ'-phase stability then all reheat treated specimen were performed with long-term heating tests at temperatures of 900°C and 100°C for 200 hours. Then these obtained specimens were

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also studied by SEM. Additionally, all reheat treated and long-term heated specimens were carried out with micro Vickers hardness tests.

Results and Discussion

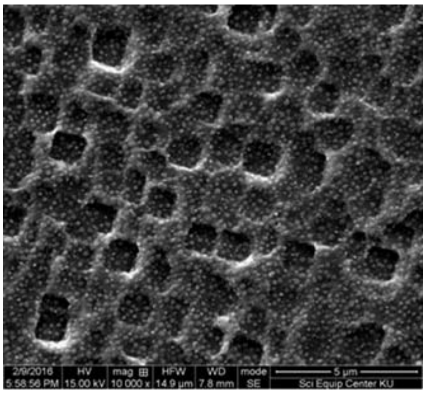


Figure 1. Microstructure of as-received specimen after 50,000 hours service time.

Figure 1 shows the microstructure of Udimet-500 after 50,000 hours service at high temperatures. The microstructure consists of both coarse and very fine γ' precipitated particles throughout the γ-matrix or it is bimodal structure. It shows that the γ' precipitated particles is much more coarsening after long-term service, which should provide lower mechanical properties.[5-7]

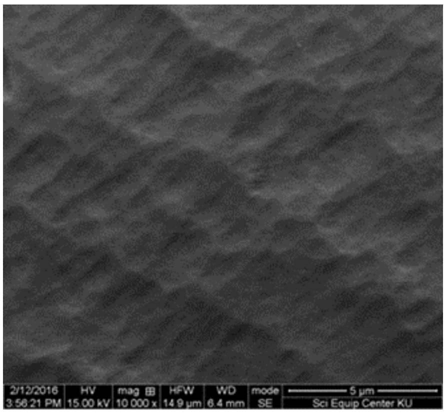
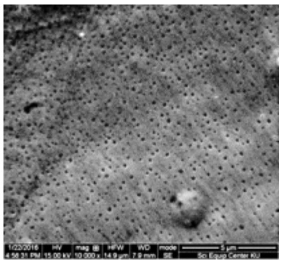
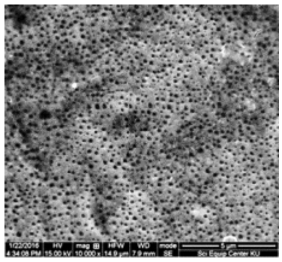


Figure 2. Microstructure of solutioning treated specimen at 1,150°C for 4 hours then air cooling.

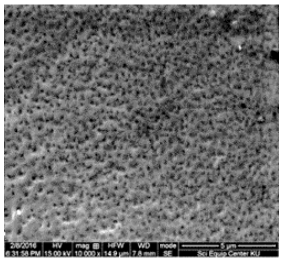
Figure 2 shows the microstructure after solutioning treatment at 1,150°C for 4 hours. After the process, with this heat treatment condition, both coarse and fine γ'-particles could be completely dissolved into the γ-matrix being already for next step precipitation aging process.



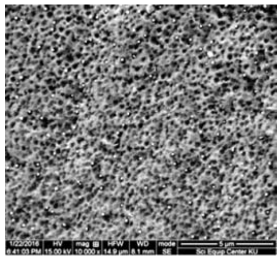
a)Aging at 760°C/16 hours.



b) Aging at 780°C/16 hours.



c) Aging at 800°C/16 hours.



d) Aging at 820°C/16 hours.

Figure 3. Microstructures of specimens after aging at various precipitation aging temperatures.

Figure 3 a)–d) show the microstructures of specimens after solutioning treatment at 1,150°C/ 4 hours and following with precipitation aging for 16 hours at temperatures of 760, 780, 800 and 820°C, respectively. From these received microstructures, it could be seen that the higher temperatures of precipitation aging provided the higher in γ'-phase area density as well as γ'-particle size comparing to these of specimen with standard precipitation aging (Figure 3a) see also figures 4 and 5.

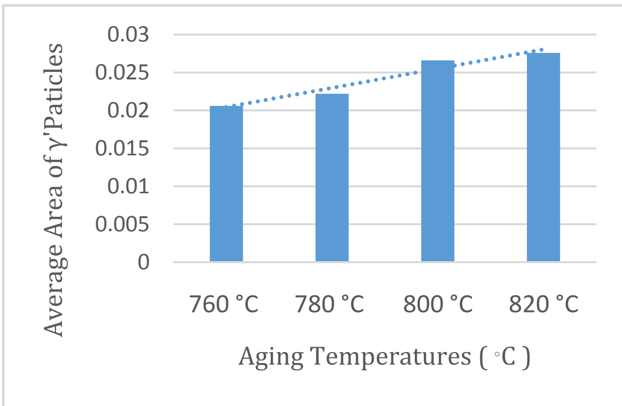


Figure 4. The relationship between γ' particles size and various agingtemperatures

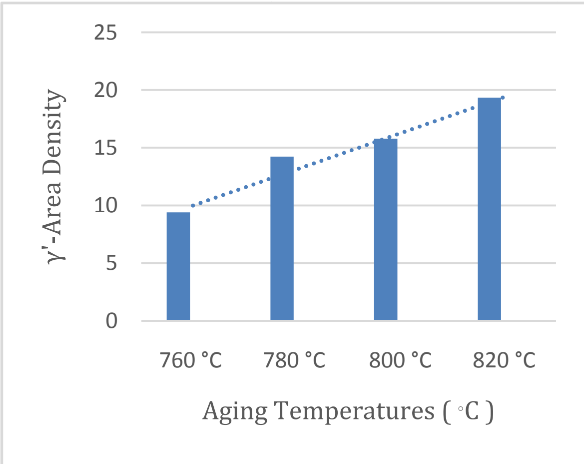
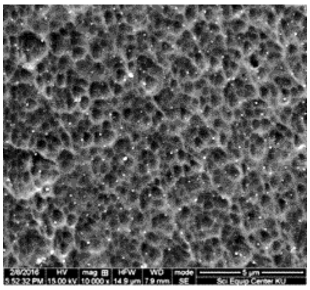
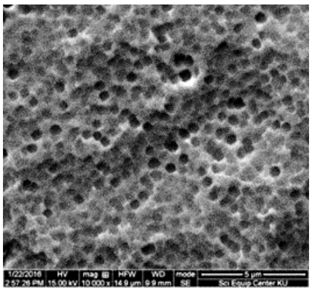


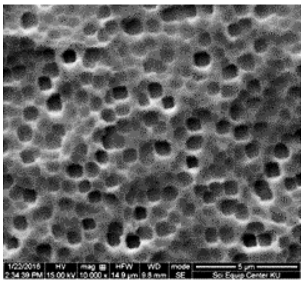
Figure 5. The relationship between γ' area density and various agingtemperatures

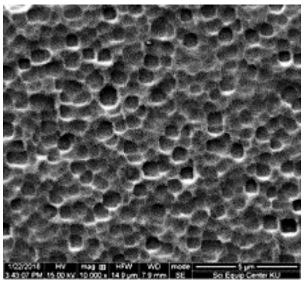




a) Aging at 760°C/16 hours and heating at 900°C/200 hours/ 200 Hrs.

b) Aging at 780°C/16 hours and heating at900°C/200 Hrs.



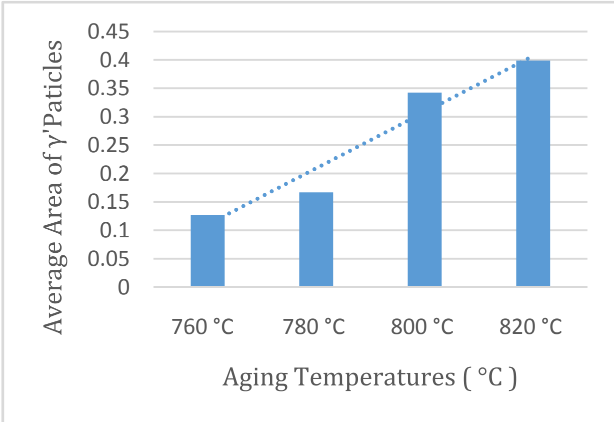


c) Aging at 800°C/16 hours and heating at 900°C/200 Hrs.

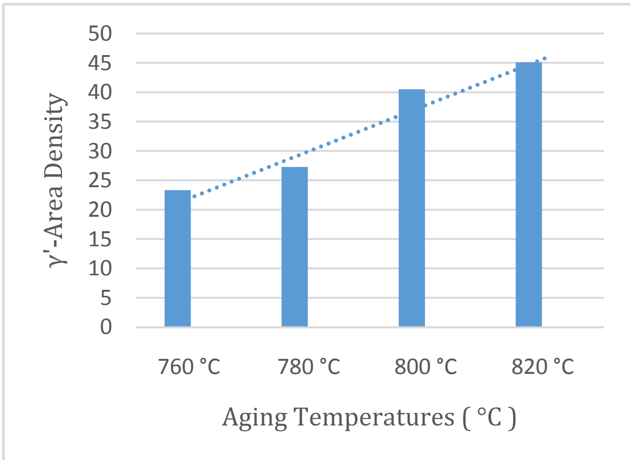
d) Aging at 820°C/16 hours and heating at 900°C/200 Hrs.

Figure 6. Microstructures of specimens after aging at various temperatures then heating at higher

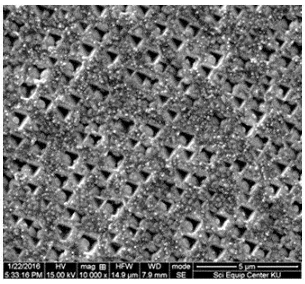
Figures 6 a) – d) show the microstructures of specimens with various reheat treatment conditions following with long-term heating at 900°C for 200 hours. From these obtained results, it was found that this heating resulted in the coarsening ofγ'-particles and γ'-phase area density comparing to those of figures 3a) – 3d). Furthermore, the higher aging temperatures (800 and 820°C/16 hours) provided dramatically increasing in both size and area density of γ'-particles, see figures 7 and 8.



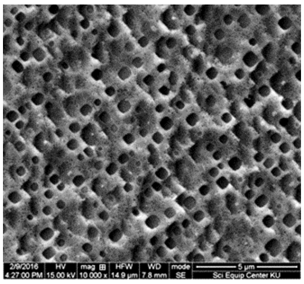
Figures 7. The relationship between γ' particles size and various agingtemperatures after heating at 900°C/200 hours



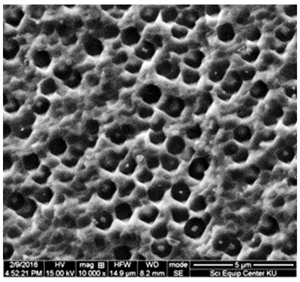
Figures 8. The relationship between γ' area density and various agingtemperatures after heating at 900°C /200 hours



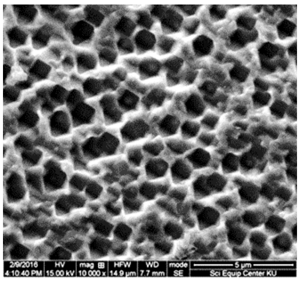
a) Aging at 760°C/16 hours and heating
b) at 1,000°C /200 Hrs.



b) Aging at 780°C/16 hours and heating at 1,000°C/200 Hrs.



c) Aging at 800°C/16 hours and heating at 1,000°C/200 Hrs.



d) Aging at 820° /16 hours and heating at 1,000°C/200 Hrs.

Figure 9. Microstructures of specimens after aging at various temperatures then heating at higher temperature at 1,000°C for 200 hours.

Figures 9 a) – d) show the microstructures of specimen with various reheat treatment conditions following with long-term heating at 1,000°C for 200 hours. The received results clearly show the much higher effect of higher heating temperature on γ'-particle coarsening than those of figures 6a) – 6d). There is also the same trend asit was found in long-term heating 900°C for 200 hours that the higher aging temperatures (800 and 820°C/16 hours) resulted in rapidly increasing of both size and area density of γ'-particle, see also figures 10 and 11.

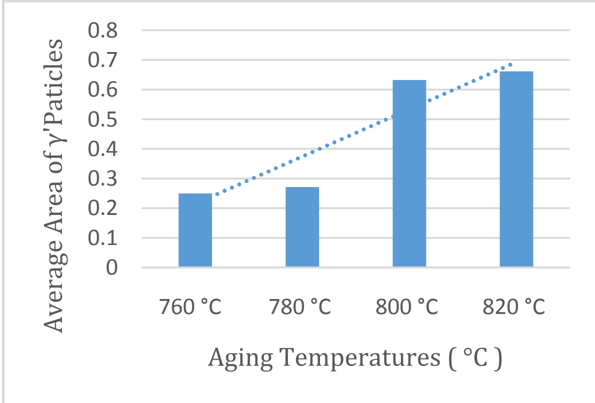


Figure 10. The relationship between γ' particles size and various agingtemperatures and heating at 1000°C/200 hours.

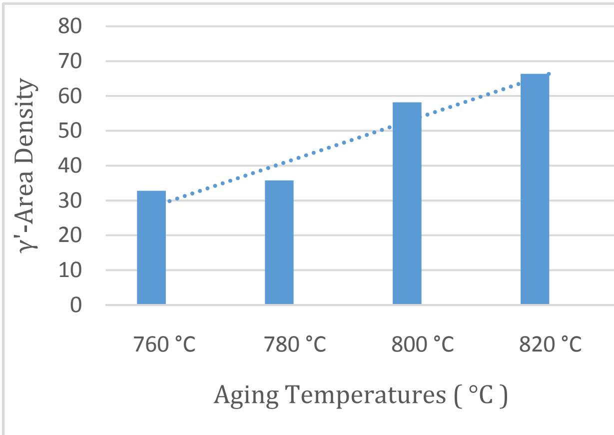


Figure 11. The relationship between γ' area density and various agingtemperatures and heating at 1000 °C/200 hours.

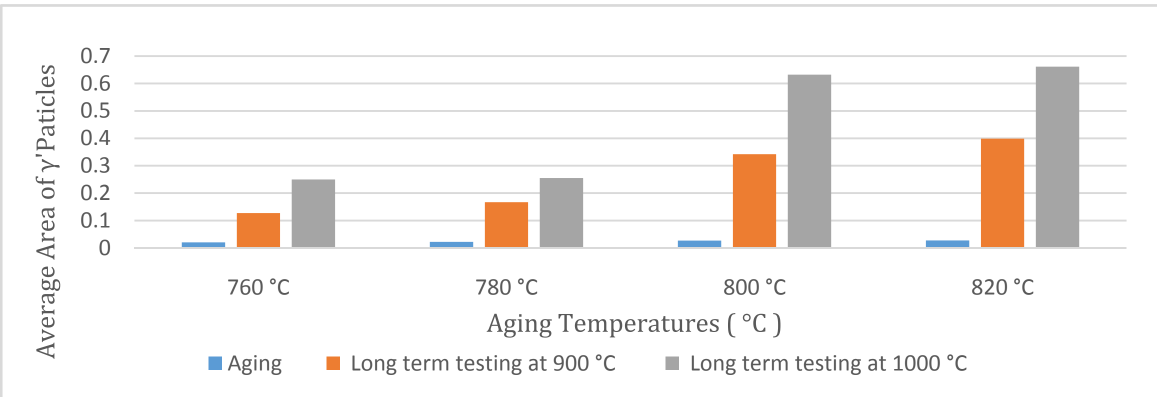


Figure 12. The relationship between γ'-particles size and various agingtemperatures after heating at high temperatures

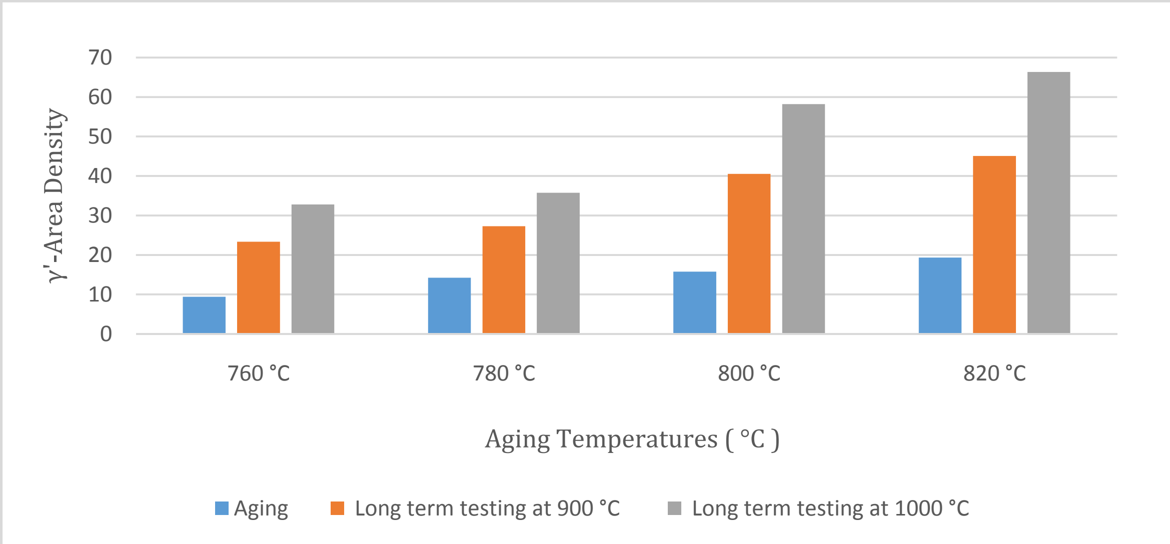


Figure 13. The relationship between γ'-area density and various agingtemperatures after heating at high temperatures

Form overall results re-expressed in Figures 12 and 13, which show the effects of aging temperatures and long-term heating temperatures on size (average area of γ'-particle) and γ'-phase area density, respectively. It could be summarized that long-term heating at high temperatures provided much more effect of both very rapid γ'-particle coarsening and increasing in γ'-phase area density. This result was much more pronounced when the specimens were performed with the higher precipitation aging temperatures of 800 and 820°C for 16 hours.

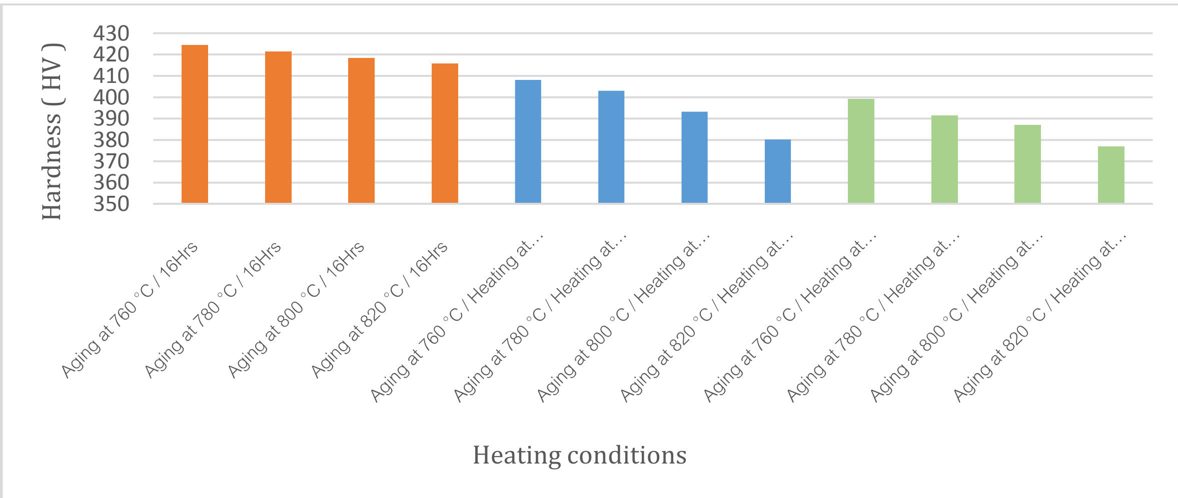


Figure 14. The relationship between hardness and reheat treatment conditions

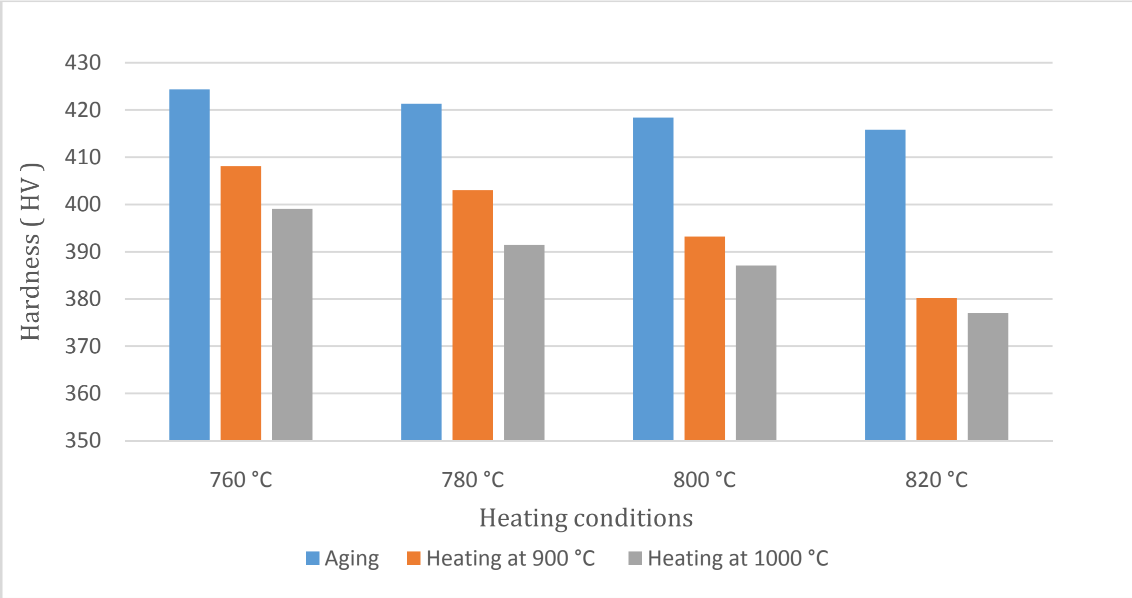


Figure 15. The relationship between hardness and various agingtemperatures after heating at high temperatures

Figures 14 and 15 show the obtained hardness results from specimens with various reheat treatment conditions and long-term heating tests. From these obtained results, it was found that the higher of precipitation aging temperatures resulted in lower hardness values. Furthermore, it was also found that the higher heating temperature resulted in much lower hardness values.(6-10) From these, it could be concluded that the hardness ismore dependanton the size of γ'-particle much more than the γ'-phase area density, which usually provides higher hardness, see details in Figures 16 and 17.

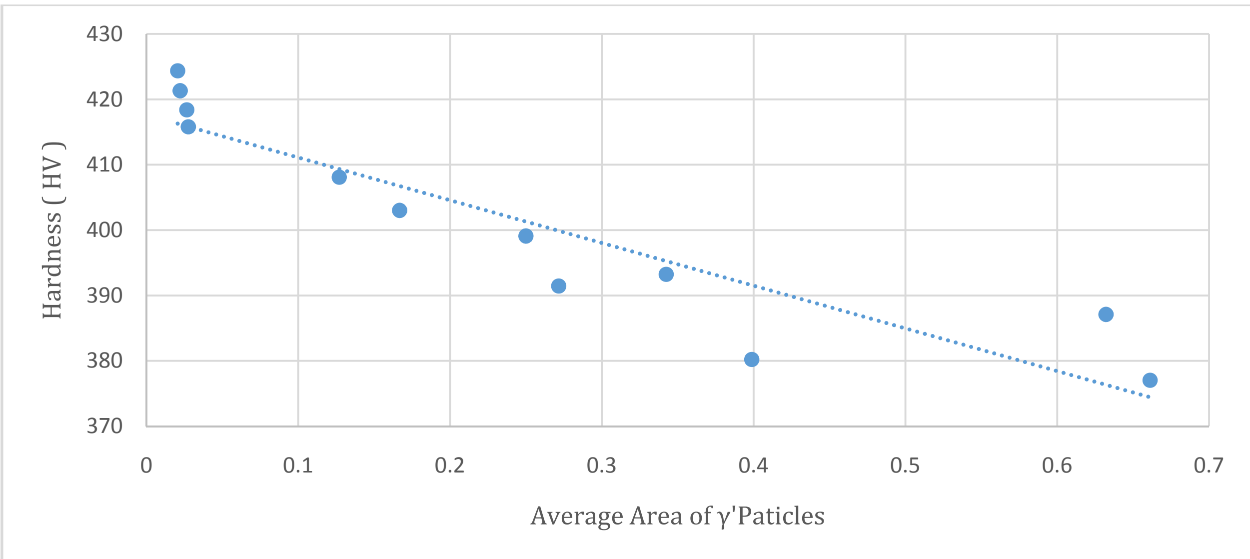


Figure 16. The relationship between hardness and γ' particles size

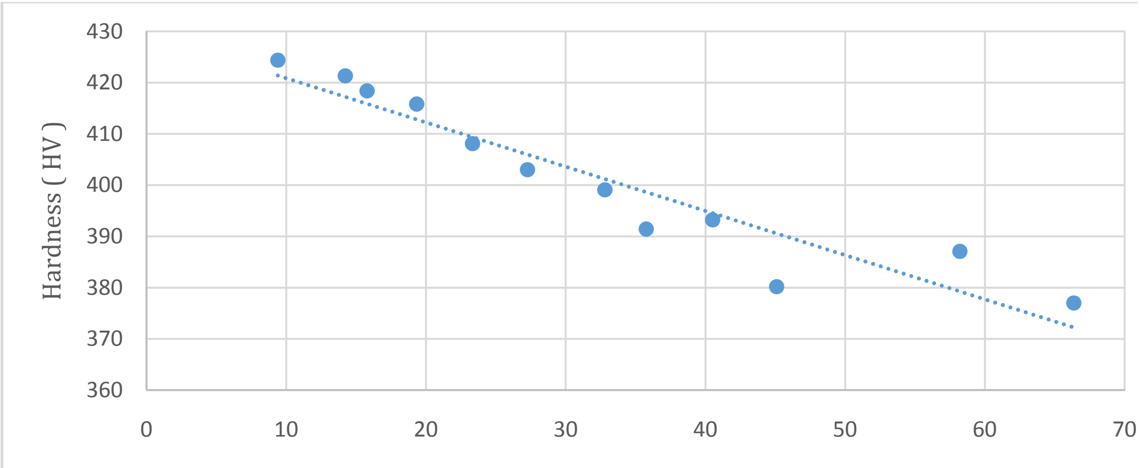


Figure 17. The relationship between hardness andγ' area density

Conclusions

1. Higher precipitation aging temperature provided higher results in size and area density of γ'-particles but lower in hardness.

2. Higher heating temperature provided also both increasing in size and area density of γ'-particles but decreasing in hardness.

3. The effect of size of γ'-particles on hardness was much more pronounced than that of γ'-phase area density.

4. The lowest precipitation aging (standard aging temperature) form temperature even provided the lowest area density and size of γ'-particles but resulted in the highest hardness and the most γ'-phase stability after long-term heating tests.

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