DEVELOPMENT OF CONTINUOUS ANNEALING HEAT TREAT PARAMETERS FOR INCONEL 718 STRIP STOCK

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Abstract

As part of the optimization of the fabrication process for Inconel 718 airfoils produced by cold, contour rolling from AMS 5596 strip stock, continuous annealing heat treat parameters were developed. Variables studied included temperature, time at temperature and cooling rate. A cycle of 954°C (+/- 45°C) for 90 seconds (minimum) with a cooling rate of 180°C/minute (minimum) was found to adequately reduce cold rolled hardness. To assist in determining when an in-process anneal was required, the relationship between cold rolled reduction in thickness and as-rolled hardness was established.

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Introduction

The sluggish precipitation kinetics of the γ'' strengthening phase in Inconel 718 results in many attractive fabrication characteristics such as a resistance to weld strain age cracking and being readily workable in the as-solutioned condition. The sluggish precipitation kinetics are primarily due to the body centered tetragonal structure of the γ'' precipitate (ref 1) and the relatively low diffusivity of columbium (compared to aluminum and titanium). In addition, the body cenetered tetragonal γ'' structure results in significant strengthening at intermediate temperatures (up to 649°C) however limits the maximum use temperature relative to other superalloys due to its metastable condition and strong driving force for transformation (references 1,2) to the non strengthening δ phase. The above fabrication and strength characterisitics make Inconel 718 a strong candidate for turbine engine compressor airfoil applications where good intermediate temperature strength, high cycle fatigue resistance and ease of fabrication are required. At P&W a process to cold contour roll compressor airfoils from strip stock was developed as a low cost fabrication process. A schematic of the process is presented in Figure 1 and it consists of contour rolling two airfoil shapes (trailing edge to trailing edge) across the strip followed by cutting of the airfoil edges ending with stamping the required camber and twist and removing the airfoils from the strip. An integral part of this process is the successful continuous anneal of the strip after the cold rolling operations. The development of the continuous anneal heat treat parameters are presented in this paper.

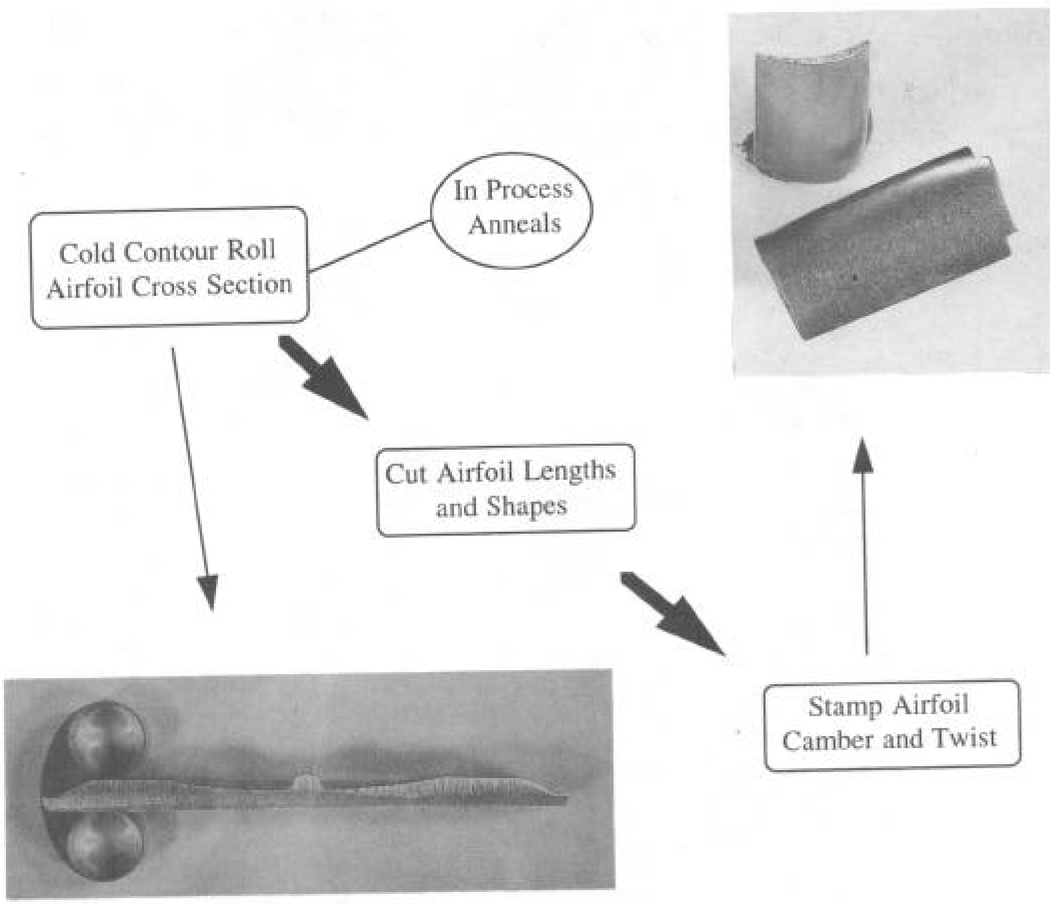

Figure 1.
Schematic of Inconel 718 Strip Stock Compressor Vane Fabrication Process.

Details

Material for this program was provided by Pratt & Whitney's Manufacturing Division as rolled strip stock in the ready to be annealed (as contour rolled) and as received (mill annealed) conditions. Heat codes and experimental usage for the material are presented in Table I. There were four tasks undertaken in the project.

Table I

Heat Code	Task I	Task II	Task III	Task IV
YMZG (As Rolled)	X	X		
YMZP (Mill Annealed)			X	X

Task I. The Effect of Annealing Time and Temperature on As-Annealed Hardness and Grain Size was investigated by annealing 1.1 cm long sections of production rolled strip stock for times ranging from 2 minutes to 60 minutes over the temperature range 899°C to 1038°C. The complete heat treat matrix is presented in Table II. All samples were water quenched from heat treatment to eliminate the cooling rate factor on the as-annealed hardness of the strip stock. Following heat treatment, transverse segments were metallographically evaluated for hardness and grain size.

Table II
Heat Treatment Matrix to Evaluate the Effect of Time and Temperature on As-Annealed Hardness and Grain Size. All Material was Water Quenched From the Annealing Cycle.

Temperature	2 Minutes	5 Minutes	10 Minutes	30 Minutes	60 Minutes
899 (°C)	X	X	X	X	X
927 (°C)	X	X	X	X	X
954 (°C)	X	X	X	X	X
982 (°C)	X	X	X	X	X
1010 (°C)	X	X	X	X	X
1038 (°C)	X	X	X	X	X

Task II. The Effect of Cooling Rate on As-Annealed Hardness was evaluated by processing production rolled strip stock through a 982°C/5 minute anneal followed by cooling at rates of 18°C/minute to 816°C/minute. Table III shows the cooling rates evaluated and the procedure used to attain them. Slower cooling rates (< 225°C/minute) were achieved by using a microprocessor controlled furnace with the faster rates achieved by using various combinations of insulating materials and cooling mediums. The faster cooling rates were measured by welding two pieces of strip stock together and inserting a thermocouple (Figure 2). Following heat treatment, all samples were evaluated for hardness.

Table III

Heat Treatment Matrix to Evaluate the Effect of Cooling Rate From The Annealing Cycle on As-Annealed Hardness. All Material Processed Through a 982°C/5 Minute Cycle.

Cooling Rate	Insulating Material	Quench Media
833 (°C/Minute)	None	Forced Air
444 (°C/Minute)	None	Still Air
222 (°C/Minute)	Nickel Foil	Still Air
69 (°C/Minute)*	None	Argon
33 (°C/Minute)*	None	Argon
25 (°C/Minute)*	None	Vacuum
11 (°C/Minute)*	None	Vacuum
6 (°C/Minute)*	None	Vacuum

* Heat treatment conducted in microsprocessor controlled furnace.

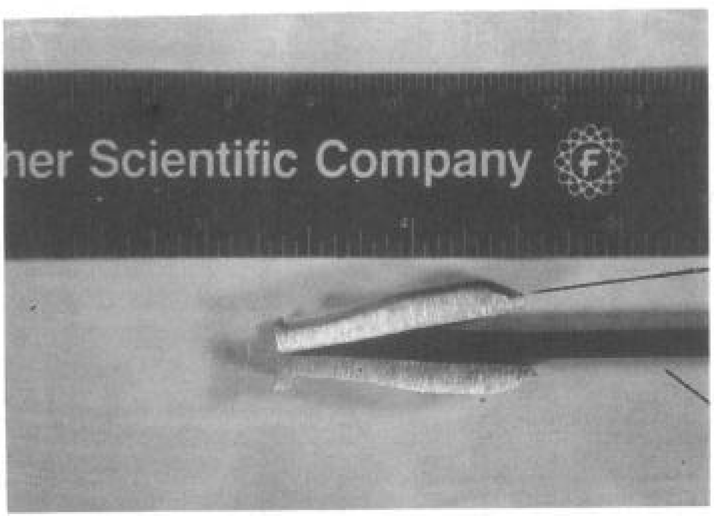

Figure 2

Strip Stock Segements Welded Together With a Thermocouple Inserted to Measure Cooling Rates From the Annealing Cycle

Task III. The Effect of Cold Work on Hardness and Strength was determined by taking as-received (mill annealed) strip stock and cold rolling it to reductions in thickness over the range 0% to 60 % in increments of 10%. The rolling schedule was established so that all material finished at .127 cm thick for machining into flat tensile specimens for room temperature testing. Transverse metallographic sections were also evaluated at each reduction in thickness for hardness.

Task IV. The Effect of Removing Hardening Elements from Solid Solution on Cold Rollability was evaluated by processing segments of the as received (mill annealed) AMS 5596 strip stock through a 899°C/16 hour cycle to precipitate the Nb in solution out as the non-strengthening δ phase prior to cold rolling (the microstructure is presented in Figure 3). After heat treatment, the strip was cold rolled to reductions in thickness ranging from 10% to 50%. At each reduction in thickness transverse sections were metallographically prepared and hardness evaluated. Results were compared with those for the as annealed strip stock from Task III.

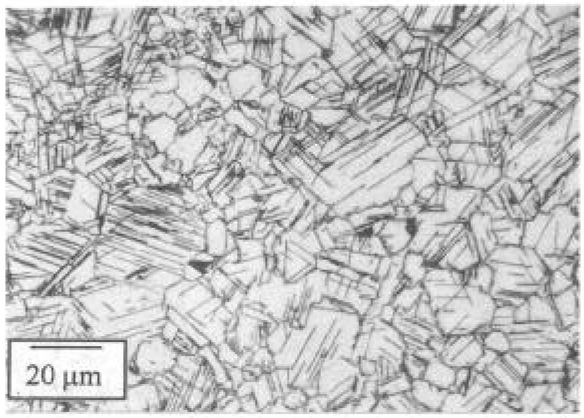

Figure 3

Typical Microstructure of Strip Stock Material Processed Through a 899°C/16 Hour Cycle to Remove Nb From Solid Solution as the Non Strengthening δ Phase.

Results

Effect of Annealing Time and Temperature on As-Annealed Hardness and Grain Size

The effect of annealing time and temperature on the as-annealed hardness and grain size of AMS 5596 is presented in Figures 4 and 5. The as-annealed hardness of AMS 5596 decreases with increasing temperatures at temperatures of 899°C and above (Figure 4). At temperatures of 927°C and above, increasing the annealing time from 2 to 60 minutes resulted in no additional reduction in as-annealed hardness. Annealing temperatures of 927°C and above were sufficient in attaining the program goal of $\leq R_B$ 95 (R_C 16). Slight grain coarsening was observed at temperatures of 1010°C above (Figure 5) with no significant grain coarsening observed with exposures of up to 60 minutes at temperatures less than 1010°C.

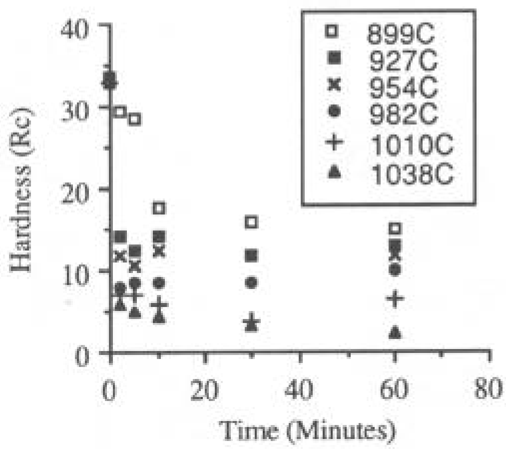

Figure 4
Effect of Annealing Time And Temperature on As Annealed Hardness of Inconel 718.

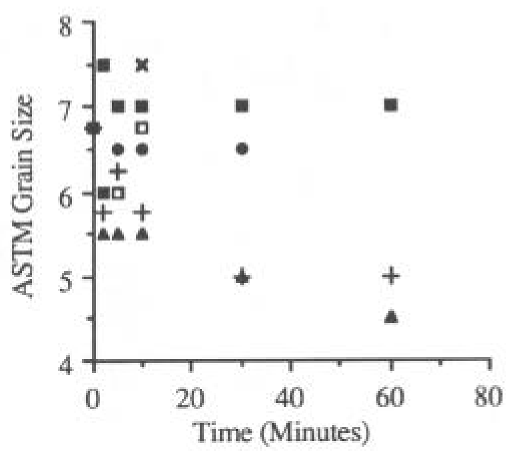

Figure 5
Effect of Annealing Time and Temperature on As Annealed Grain size of Inconel 718.

Effect of Cooling Rate on As-Annealed Hardness

The effect of cooling rate on as-annealed hardness is presented in Figure 6. At cooling rates of 69°C per minute and above the age hardening response of Inconel 718 is suppressed. At rates less than 69 °C per minute, the as-annealed hardness of Inconel 718 steadily increases reaching 35 R_c at a cooling rate of 5.5°C/min.

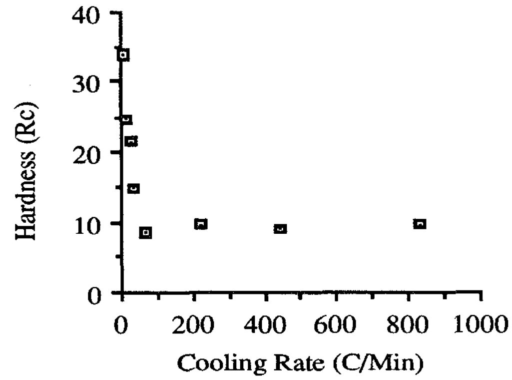

Figure 6
Effect of Cooling Rate from the Annealing Cycle on As-Annealed Hardness.

Effect of Cold Work on Hardness and Tensile Strength

The effect of cold work on hardness is presented in Figure 7. The material hardens from 14 R_c to 40 R_c after 40 % reduction and thickness reaching a hardness of 44 R_c after a 60 % reduction in thickness. Results of the room temperature tensile testing are presented in Figure 8. Strength increases from 430 MPa (Yield) and 875 MPa (Ultimate) in the as-annealed condition to 1387 MPa (Yield) and 1432 MPa (Ultimate) after a 60 % reduction in thickness. Elongation was reduced from 38.9 % in the as-annealed condition to 2.4 % after a 60 % reduction in thickness.

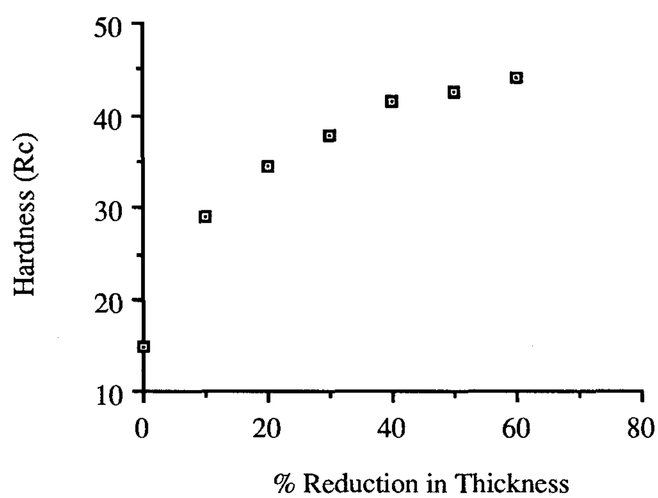

Figure 7
Effect of Cold Work on the Hardness of Inconel 718.

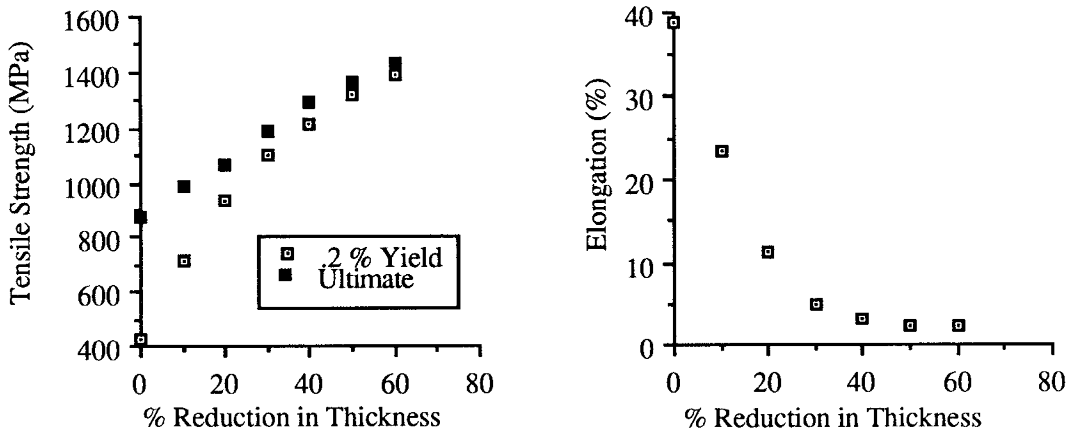

Figure 8

Effect of Cold Work on the Room Temperature Tensile Strength and Ductility of Inconel 718.

Effect of Removing Hardening Elements from Solid Solution on Cold Rollability

As rolled hardness of material processed through a 899°C/16 hour cycle is compared with the as-annealed material in Figure 9. Similar hardening rates and maximum hardness levels were observed indicating that the cold rollability of Inconel 718 is not improved by removing the hardening elements from solution.

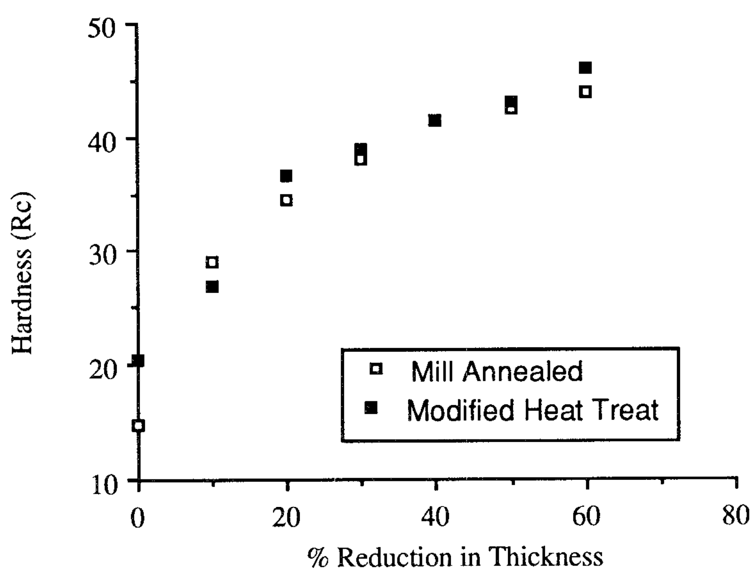

Figure 9
Effect of a Modified Heat Treatment on the Rollability of Inconel 718.

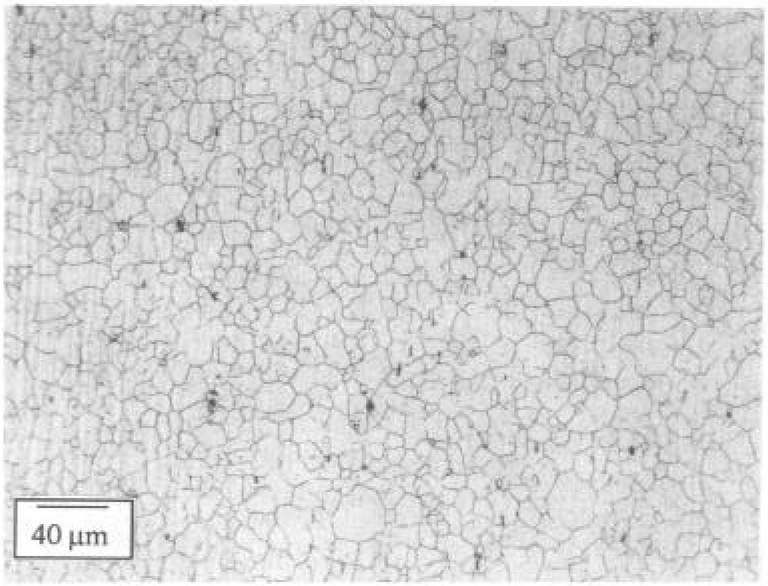

Figure 10

Typical Microstructure of Strip Stock Material Cold Rolled and Processed Through the Recommended Continuous Annealing Cycle.

Conclusion

Based on the results of this work a cycle of 954°C (+ 90°C/- 45°C) for a minimum of 90 seconds with a cooling rate of 180°C/minute (minimum) was recommended for the continuous heat treatment of Inconel 718 strip stock. The microstructure of material processed through the recommended cycle is presented in Figure 10. A preconditioning heat treatment to improve cold rollability was not recommended.

References

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2. R. Cozar and A. Pineau,Met Trans 4 (1973), 77