Machinability improvement of Inconel 718 during heat treatment - A review

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Abstract. The requirement for high strength and heat resistant materials is growing especially in aerospace applications. However, due to mechanical properties such as high wear resistance, resistance to abrasion, and low thermal conductivity, these materials are often difficult to machine, which makes cutting forces and cutting temperatures too high and leads to short tool life. Differences in material microstructures due to differences in chemical composition, casting, and forging techniques and heat treatment may lead to variations in machinability. Different types of heat treatment are performed on the alloy Inconel 718. The alloy is characterized by the austenite matrix with a unique microstructure, which includes the matrix γ, sediment, γ′, γ″, δ and carbide. The use of annealing process at different heating temperatures and rates of cooling enhances easy turning and longer tool life. In annealing, metal is heated above the critical temperature and cooled slowly in a medium over some time. Adhesion and hardness properties of the alloy cause short tool life. Elemental distribution, grain morphology, and texture of the built material are carefully evaluated using various material properties methods including TEM, SEM, EDS, and OM. Reviewed.

1. INTRODUCTION

Alloy 718 is a source of heavy-duty material, used mainly in the form of a manufactured product as different types of engine parts. It has good mechanical properties in cryogenic, medium, medium temperatures and shows poor thermal properties. Its main uses have been aircraft turbine engines, rocket motors, and, more recently, nuclear reactors. In 1966, it was one of the largest tonnage engines, of aircraft and others, produced one million pounds. The Inconel is difficult to cut, the cutting tool usually wears out quickly while machining, so it is very important to choose the right cutting parameters for a particular machining operation. The Inconel 718 is a nickel-based superalloy which is very hard to machining or cutting operation of materials due to the high hardness, high stability at elevated temperatures, adherence to the tool, and work surface. The structures which make important material also responsible for the tool's inability, and poor machinability. An Inconel 718 microstructure is composed of γ solid matrix solution rich in Ni, Cr, and Fe (Table 1) along with gamma prime, and gamma double prime such as γ′, and γ″,δ-phase. Gamma prime and gamma double prime is the precipitate phases and δ controls grain size and remains at the grain boundary. The material property i.e., machinability was well explained by the hardness values of all the parts to be machined, cutting force, surface texture, and tool life.
Table 1. Inconel 718: chemical composition

| Element | Max  | Min  |
|---------|------|------|
| Ni      | 55.00| 50.00|
| Cr      | 21.00| 17.00|
| Fe      | Rest | 4.75 |
| Nb      | 5.50 | 2.80 |
| Mo      | 3.30 | 0.65 |
| Ti      | 1.15 | 0.20 |
| Al      | 0.80 | 0.20 |
| Co      | 1.0  | 1.0  |
| Mn      | 0.35 | 1.0  |
| C       | 0.08 | 0.3  |
| Si      | 0.01 | 0.3  |
| P       | 0.3  | 0.1  |

2. LITERATURE REVIEW

2.1 Tool wear
Mall et. al. [1] Tensile residual stress after machining of Inconel 718 remains at the surface resulted in poor machinability. The surface roughness optimized using cutting depth cutting feed and speed with nose radius of the cutting tool. It is observed i.e. Carbide tool unable to machining heavy depth of cut. Just The most significant level of surface quality is accomplished by the carbide tool on the Inconel 718. It isn't used for machining of heavy cut. Performance shows only light-duty machining, turning, and finishing or semi-finish operation. Rahman et. al.[2] Inserts Flank wear, surface roughness, and cutting forces are the performance tool life indicator. Two types of inserts observed on the CNC lathe machine, which is physical vapor deposition, grades EH20Z-UP, and AC25 chemical vapor deposition. Improved Tool life observed with an increased secondary edge clearance angle from 5° to 45°. And tool life gets reduced when the secondary edge clearance angle decreased from 45° to 5°. While increased speed or feed, the tool life of the inserts gets reduced. This is usually due to the experienced high cutting forces, low thermal conductivity, and the tendency to adhere and harden the material. Resulting in excessive heat at the cutting edge. Bushlya et al [3] Nickel-iron based these Inconel 718 alloys reduce its machinability due to mechanical and thermal properties at high temperatures, wear resistance, resistance to heat transfer, and abrasion during machining. Currently low performance, at Lower cutting speeds of around 60 m / min in traditional carbide tools. Requires improved performance, more cutting speed, need modified tools. Prefer to use PCBN tools, suitable for machining high cutting speed, but certain depth of cut. Eren and Birol [4] The resulting tool wear is a combination of mechanical and chemical interactions between the tool and the workpiece during machining of nickel-based alloy. The following wear patterns can be found in cutting alloys of superalloys tips: expansion wear, adhesive wear. Effect of Tool tip radius on some mechanical properties, such as residual stresses and surface roughness. Some of the more controversial problems in selecting optimal shear parameters and tool nose radius.

Addona et al [5] Turning operation is performed with coated carbide insert specification of K 05-K25 and wnma 060408 grade. The average burn rate of the tool is very low at lower cutting speeds due to the low temperature on the cutting zone. High cutting speed the tool is wearable at a faster rate with larger patterns of tool failure such as heavy notching is found. Better tool performance of a coating is a certain temperature range behind that tool is unable to work. Pande and Sambhe [6] At high cutting speed Lower performance was found on Inconel718 with carbide tips. Uncoated carbide tips are better than coating tips because high cutting speed disrupts surface integrity, Coated tips unable to improve tips performance at high speed. Surface finishing is achieved as a good value range from 45 to 55 m/min. Cutting speed of carbide tips is higher than CBN tips for better surface finish. Improved tool life was observed when the secondary clearance edge angle increased. Tool life of carbide with cutting range 120 m/min to 240 m/min is high as compared to the CBN tool. Also, better tool life is a range above 250 m/min with ceramic tips on Inconel 718 alloy. Xavior et.al [7] three tips are used for turning on the lathe. TiAlN carbide, CBN, and ceramic on Inconel 718 alloy, it is found that decreases wear at cutting speed increases for ceramic and also CBN tools. Wear decrease while lowering the speed at Vc = 60 m /min for the Carbide tool, and minimum wear found for CBN and also Ceramic tips tool at 120 m/min, minimum wear found at speed 60 m/min for carbide tips. Altin et al [8] Wear rate is a minimum of ceramic tips at higher cutting speed and high at lower cutting speed. Four types of wear are found in ceramic inserts, flank and notch wear are using round inserts and flank and carter wear are found in square types tips. Another type of wear that is plastic deformation found in both
types of inserts. The maximum tool life is found at 250 m/min and lower tips tool life is found below that.

2.2 Microstructure
Tucho et al.[9] to [ ] Post-treatment needed to obtain the desired conditions and the required properties for a part made from selective laser melting print technology of alloy 718, the initial hardness of these parts is more than parts made from wrought techniques. These kinds of post-treatment as a pre-aging treatment needs to evaluate effects at 1100 °C or 1250 °C on microstructure, hardening properties, and microsegregation. Printed samples have a greater amount of complexity due to numbers of heating and cooling runs during manufacturing than solutions containing heat-treated samples. During a solution heat treatment at 1200°C leaves and other phases are completely dissolved along subgrain boundary. After recrystallization during the solution treatment grain coarsening effect was found. Bacaltchuk et al.[10] The magnetic behavior of thick silicon (GNO) flat material, is mainly governed by two microstructural factors: final texture and normal grain size. The shape, or crystalline preference tendency, is influenced by energy, mobility, and anisotropy in the energy resulting from grain boundary migration during recovery, grain mobility, and grain growth. Magnetic field strength has a marked effect on the application of structural flexibility and natural exposure to ferrous alloys. Samples are placed in the magnetic field strength of 8 T which is the highest field is used to maximize their influence in improving texture. Kishan et. al. [11] the degree of stabilization depends on γ' and γ'' distribution in the γ matrix. Chemical composition of strengthening of γ'' is Ni₃Nb at temperature 720°C, γ’ is Ni₃Al or Ti at 620°C, δ-NbC at 650°C, which is stable and γ'' is metastable transfer into the delta on high temperature which reduces the hardness of a material. Delta prevents grain mobility and grain growth.

2.3 Grain size
Mukhtarova et al [12] The superalloy Inconel 718 produced by the SLM techniques had a particularly good gamma size and diffusion dislocation, unlike any other conventional material. Higher torsion pressure of the superalloy resulted in the refinement in the microstructure and increased Microhardness in both alloys. When deformed superalloy annealed at 600°C for two hours resulted in increased microhardness. Microhardness of selective laser melting techniques is higher than that of conventional techniques. Higher microhardness shows it is hard material for machining. ZHANG et al.[13] Microstructure and tensile behavior of superalloy k4169 were evaluated during undercooling. With an increased rate of undercooling dendrites morphology, phase of intergranular and grain size was found to be changed. At high undercooling uniform, Laves phase distribution and improved strength and mechanical properties were found. Enes Akca and Gursel [14] The Inconel 718 has been progressing in the way that it is used by the defense industries never to replace any other by combining its finest mechanical strength. The Strength of ns state of Inconel 718 alloy depends on grain size at room temperature, more strength found at small grain size acceptable at 1920 MPa. It is desirable to use NS state Inconel 718 after heat treatment when it has immense strength and adequate ductility. We need to develop an exceptional heat-treatment process for a good service life of these alloys. Moiz [15] Grain size measured two types of sample heat-treated at various temperatures of Inconel 718. Results of mechanical test for grain size found that hardness and tensile property decreases with increased grain size during improving creep life. Small grain size with lower ductility was found at room temperature. Complete dissolution takes place of γ' and partial γ'' phases of Inconel 718 using solution heat treatment about 1050 °C for two hours. And the same temperature delta into a matrix and 960°C δ phase found in along grain boundary which lowers ductility with increased grain size, for better strength needs small grain size.

2.4 Hardness
Hernandez et al.[16] Poor machinability, reduced tool life due to precipitated phases γ', γ'' and δ are also responsible for the high hardness of Inconel 718. Carbides formation takes place at a temperature range of 600 to 670°C and samples strengthened at a temperature range 600 to 648°C speedy growth
of γ″ which are verified and found maximum 360 HV hardness value. Material indicating phase changes at range from 760 to 820 °C. 230 HV decreased hardness value found at 900°C. Material shrinkage at a range of 820 to 950°C, which indicates the formation of a higher value of the delta phase. MAJ et al. [17] Tensile and hardness properties of Inconel 718 were evaluated after heating and soaking different range of temperature, there is a functional relation between initial aging and reheating at a temperature of 650°C-900°C with 5-480 min. Factors that were influencing changes of microstructure at different stages of strength are found. At a temperature range 650-750°C, γ″ phase mostly nucleates homogeneously and it is the highest strength. Phases are found formed heterogeneously at 850°C and above, material weakens longer annealing at 800°C. Schirra [18] Advantages of modified heat treatment are an improvement of required property and reduced hardness value and cycle time of the process, the result indicates that drop of 7RC value of hardness and reduce 30 percent of the cycle time of heat treatment process. Modification is achieved by the controlled rate of cooling and increased heating temperature and homogenization cycle time. Precipitation time is shorter with a higher solution time and longer with lower solution time.

2.5 Heat treatment
Kuo et al. [19] Uniformly distributed delta phase at grain boundary depends on aging time, the delta phase increases with increasing aging time. A result from EDS analysis shows that the delta phase is the chemical composition of NbC, remains grain boundary which controls grain mobility and grain growth. Inconel 718 is heat-treated Three different kinds of heat treatment process these resulted in grain size to 170μm, 160μm, and 155μm. The delta phase unchanged after aging 955 °C but changed 650 °C to 980 °C. Sui et al. [20] Laves phases of laser-assisted melted Inconel 718 found changed long-striped to granular shape at a temperature 105 °C for 15 min. The shape does not change but a small fraction of volume decreased of leaves phase at a temperature 1050 °C for 45 min. Volume fractions, lengths, width, and aspect ratios calculated with Image-Pro-Plus software. Due to niobium micro-segregation always affected Laves phase formation, resulted in coarsening and inhomogeneous effect on γ″ phase distribution. To eliminate long-striped Laves phases and uniform γ″ phase, need heating a specimen at a temperature 1050 °C for 15 min. After heating above 15 minutes and up to 45 minutes, Laves phase morphologies do not change but the volume fraction decreases when time extends to 45 min. Ghosh et al. [21] Ball indentation technique observed with optical microscopy of a specimen Inconel 718. Specimen of Inconel 718 solution heat-treated one h at 940 °C. And 1040 °C with water quenched and aged at a temperature 720 °C, for 8 h and cooled in the furnace. BIT pointed out that the strength of the material was found to be greater than other heat-treated specimens. After solution treatment decreased strength was observed and improved strength was found after aging. Anbarasan et al. [22] Homogenization, solution annealing, and precipitation hardening are the standard heat treatment processes used for Inconel 718. Furnace cooling improves hardness due to precipitate strengthening both phases γ′, and γ″. While lower hardness was found due to a faster rate of cooling in ice brine quenching, there is an absence of precipitation in ice brine quenching.

Jambor, et al. [23] At high temperature, after sufficient time gamma double prime phase of Inconel 718 transferred into delta phase was found, it is a stable phase, crystal structure is orthorhombic, and gamma double prime is a metastable phase. δ phase present in an increased amount is unacceptable but it remains grain boundary prevents grain growth. At 700°C with cyclic loading large amount of delta phase found which prevents grain interiors. transfer of δ phase particles occurs in some preferred Crystallographic planes. Decreased hardness value was found at an increased amount of delta phase particles. Suia et al. [24] Observed the tensile behavior of solution treatment on Inconel 718 made from laser metal deposition techniques. Two types of heat treatment regimes were taken for an experiment, which is S treatment 1100°C for 0.5 h with WQ and 720°C -8h with FC to 620°C-8h with AC. L treatment is the same as the first type but the first soaking time is 1 hour instead of .5 hours. Some large grains with columnar crystals found in s types of heat treatment and all large with equiaxed grains were found in L types of treatment. S samples indicate that recrystallization was not completed and L types of treatment equiaxed grains indicate that recrystallization was completed.
Sample L shows recrystallization is higher and uncompleted recrystallization indicates in S types. Hall and Beuhring [25] for specific forming operation certain solution treatment does not make metal soft enough temperature must be raised, but increased grain size must be taken into consideration. To required metal to be uniform soft, need rapid cooling for a thick section in water, and spray quenching for thin section. To improve ductility and reduce the hardness of nickel and nickel-base superalloy need high-temperature heating with a certain time and followed by slow rate cooling.

2.6 Heat treatment and magnetic field
Patwari et. al.[26] Magnetic field applied during the turning process on annealed mild steel. Both effects of heat treatment and magnetic field found in reduced hardness and improved machinability. Enhanced surface finish, continuity of chips, and less adhesion were found by the use of a magnetic field on an annealed specimen during turning. Increased tool life was observed due to the combined effect of heat treatment and the magnetic field. Li et. al.[27] A steady magnetic field used during heat treatment on superalloy DZ483 and evaluated mechanical behavior and microstructure. Grain coarsening of the precipitates and diffusivity of alloy found reduced using a steady magnetic field. A delay of their splitting led to decreases in their average size was found. Precipitates Small size of $\gamma'$ indicate good tensile strength using a magnetic field during heat treatment. Li et.al.[28] Alternating magnetic field applied on DZ483 superalloy during heat treatment and the combined effect on segregation, and microstructure evolution was investigated. The evolution of $\gamma'$ precipitates in the alloy was observed. Accelerated morphology transition reduced segregation and increased the average particle size was found with aid of alternative magnetic field during heat treatment. Use of a magnetic field applied during heat treatment, average particle size was found larger as compared to without magnetic field. The AMF applied during aging treatments modifies morphology and the average size of $\gamma'$ precipitates. Bozorth and Dillingeret [29] Material heated at about 1000°C and cooled slowly, and the magnetic field applied during cooling at different intervals, again heated to 500°C maintained it certain time and cooled slowly up to room temperature. The magnetic effect was found in this two materials, permalloy contains 65 percent nickel and perminvar 20 percent nickel. The change of magnetic properties with the application of the magnetic field was found at a temperature range 500°C. Due to local rearrangement of the material changes in magnetic properties found relief of magnetostrictive strains. The largest effects observed at a temperature range between 400° and 500°C.

Zhang et. al.[30] 42CrMo quenched structural steel tempered with and without a magnetic field between 600 and 650°C for one hour at 14T Tesla strength of the magnetic field. Magnetic field prevents cementite growth directional along boundaries of martensite plate twin on rising interfacial and magnetostrictive strain energy. Finally, particle-like cementite is found. Ludtka et.al.[31] Steel of a medium carbon is heated 850°C and cooled first in the field and then without field at different rates. Liberated latent heat found 70–90 °C increase and increased rate of decomposition due to the magnetic field of austenite. The relative decomposition is dependent on the cooling rate and cooling time. Evaluation of phase composition the volume fraction of ferrite increases from 40% to 65% on the applied 30-T magnetic field. Most of the constituent transformed pearlite to ferrite during the application of the magnetic field. The coarsening effect on the microstructure was not found due to unchanged cooling rates and chemical composition. The free energy of the material changed by the use of a magnetic field during heat treatment was found. Zou et.al. [32] Alternating magnetic field applied during solidification to reduced defects of macro-segregation and gas hole on Cu-14Fe alloy. During the initial Fe phase growth process AMF affects the nucleation of loosed grains and fusing dendrites. a magnetic field can efficiently refine the grain size in solidification. The density of the magnetic flux when exceeding 33 mT, exhibits coarsening of the grain size in a certain amount. Molodov et al. [33] Magnetic field prevents grain boundary motion and coarsening of the grains. Investigated anisotropy of the magnetic susceptibility produces a gradient of the magnetic free-energy density across the boundary at 330 and 415 °C. The combined effect of the magnetic field and annealing on cold-rolled zinc-aluminum affected the texture and microstructure evolution. The magnetic field produces an extra driving force for grain growth that takes place due to the magnetic
anisotropy of zinc. Dong et al. [34] Applied a high static magnetic field on alloy 2024 which is directionally solidified during heat treatment. Due to the magnetic field more secondary phase is observed which is more than 50 percentage dissolved into the α-Al matrix and another secondary phase becomes less due to the effect of the magnetic field. Improved mechanical properties found using a combination of heat treatment with a magnetic field.

3. MICROSTRUCTURE STUDY AND MECHANICAL TESTING:

The Microstructure, tool wear, grain size, segregation, and precipitation of the phases have been observed in reference paper and discussed in these review paper. The characterization techniques used for microstructure and machining parameter studies are Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM), Optical Microscopy (OM) and High-Resolution Photography. These techniques are reviewed in-depth and are listed in Table 2. The paper reference number indicates the serial number in the reference list attached at the end whereas the parameter details are mentioned in the short description added in the respective papers referred to in the study.

Table 2. Microstructure study of phases and structure

| Ref. No. | Abbreviation of Test | Full form | Description |
|----------|----------------------|-----------|-------------|
| 3,4,5,6,8,9,12,13,15,16,18,19,20,21,22,23,24,27,28,30,32,33,34 | SEM | Scanning Electron Microscopy | Grain Size, tool wear morphology, - and texture of materials, the 3D image of the surface of the sample, Resolution: 50nm-100nm. |
| 9,12,13,14,17,24,30,32 | TEM | Transmission Electron Microscopy | Size, morphology, and texture of materials, intergranular phase, 2D projections of the sample, Resolution: 0.2nm-10nm. |
| 9,19,22,27,28,34 | EDS | Energy Dispersive X-Ray Spectroscopy | Crystal system of material, compound phases Characterization of the sample. |
| 3,4,9,22,32,34, | XRD | X-ray diffraction | Tool wear analysis microstructure area scan and spot scan Resolution: 11nm-13nm. |
| 7,8,13,14,15,22,24,26 | OM | Optical Microscope | tool wear, chip morphology analysis, surface roughness comparison, fracture, grain size measurement morphology - and texture materials, Resolution: 0.2µm-0.7µm. |
| 5 | HRP | High-Resolution Photography | Tool wear analysis- |

The property characterization of Inconel 718 will be done by using different hardness testing methods such as Rockwell, Brinell, and Vickers test. Whereas the tensile or compression test is conducted as per different standards as mentioned in Table 2, for property analysis of the Inconel 718. Table 3 gives a detailed list of different test parameters with its ASTM standard of testing and description of the properties studied in cited reviewed references.
Table 3. Mechanical testing

| Ref. No. | Abbreviation of Test | Standard used for Test | Description |
|----------|----------------------|------------------------|-------------|
| 7,9,12,16,17,13,15,18,21,22,30 | Hardness (Rockwell, Brinell, Vickers) | ASTM E18-79, ASTM E-384, ASTM E384, EN ISO 6507, ASTM E-92 | Force applied, Indentation area, and depth of penetration decides Micro or Macro hardness. |
| 13,20,21,30 | Tension or compression | ASTM.E8, ASTM E8-95, E9-95, ASTM B557 M94, ASTM E8M-15a | Tensile or compressive strength, stress, strain, and other properties. |
| 13,15,19,20 | Other properties | - | Yield modulus, Ductility, density, fracture toughness, creep, etc. |

4. FLOWCHART

The flow chart (figure 1) shows the relation between machinability, heat treatment, magnetic field, microstructure, response parameters, process parameters, and control factor. This helps to understand how to improve machinability and control microstructure i.e. all phases in Inconel 718 with heat treatment and magnetic field.

![Flow chart of heat treatment and magnetic field](image-url)
5. DISCUSSION

Tensile residual stress, less tool life, and high cutting forces is the main problem found while machining of Inconel 718. Different types of the cutting tool is used as per certain work, as finishing operation, high-speed cutting, more depth of cut but. No tool which performs efficiently all in one. The surface of Inconel 718 which is very hard to perform different types of operation. The required surface of this alloy soft enough to a certain depth and core remains the same as before for easy machining, better surface finish, and greater tool life. Inconel 718 is hard due to two precipitation phases which are gamma prime and gamma double prime in gamma matrix. No heat transfer occurs during cutting which causes excessive heat at a cutting area, prone to adhere tool, and work surface and material become hard. The best use of carbide tools is a medium cut, not used for rough heavy cutting works it is used only finishing operation and medium cutting work and the desired quality of surface finish. At low-speed, the temperature generated is minimum but on increasing speed temperature is high so wear of cutting tool is high. On increased temperature and heavy-duty cut coated cutting tips do not shows the performance of the coating.

The main strengthening phase responsible for the hardness of the material Inconel 718, γ" is a metastable phase, at high temperature, it transforms in delta particles. A stable delta phase that prevents grain boundary mobility and grain growth. Decreased hardness was found due to more concentration of these particles which affect the interior of the grain. At room temperature, small grain size exhibits lower ductility and high strength. In solution treatment at 1050°C, complete dissolution occurs of γ' particles, some proportion of γ" phase and increased delta particles was found. As percentages of delta phase increases decreased hardness was observed. Some relational study was found in initial aged Inconel 718 reheating and cooling in different temperatures and holding time which is about 650 to 900°C and 5 to 480 minutes. At different temperatures and holding time variation of hardness was found. The weakness of material observed After longer heating about 800°C. To required reduced hardness and increased toughness, we need to apply a strong magnetic field during heat treatment which enhances texture development and grain orientation. Large grain size effect on γ" phase distribution, inhomogeneous grains due to Laves phase present in the form of long strips. To transfer long strip to the granular shape required heating at 1050°C for 15 to 20 minutes. Due to socking at a high-temperature fraction of volume decreases and shape remains unchanged.

For particular machining operation, the temperature does not make the material soft by solution treatment, the temperature should be raised to soften the material. But after high-temperature grain size of the material become large. Required experimental investigation for the different magnetic fields for different temperatures to prevent grain size, modification of texture, and grain orientation. Specimen of annealed mild steel turned on lathe machine with a magnetic field, less adhesion, improved surface finish, Increased tool life, and chips continuity was found. While precipitation, the Grain coarsening effect was found of the DZ483 superalloy during the magnetic field. We need to use a steady magnetic field for the effect of minimum grain coarsening. With the use of the alternating magnetic field, it reduces microsegregation, increased particle size, and reduced gas hole defect was found of a DZ483 superalloy during heat treatment.

Decomposition of austenite, increased ferrite volume percentage about 30 to 40 percentage, increased pearlite to ferrite transformation, and reduced coarsening was found of medium carbon steel heated with 30T magnetic field about 800°C and different cooling rates.

6. CONCLUSION

While using PVD grades EH20Z-UP and CVD AC25 cutting tool, excessive heat at the cutting zone and reduced tool life was found due to high cutting force, less thermal conductivity, prone to adhere
surface, and harden the material. Reduced tool life was found as speed or feed increased, and increased depth of cut. The hardness of Inconel 718 due to its precipitated phases as gamma prime, gamma double prime, and leaves phases. The presence of delta phase at grain boundary at proportion does not affect hardness properties but the increased amount of delta particles at grain boundary which affect the interior of the grain due to which reduced hardness was found. At high-temperature gamma double prime which is metastable convert into the delta. A stable delta phase is a form of NbC which prevents growth and mobility of grain. The use of a magnetic field with heat treatment enhances texture development and microstructure modification. To obtain required property and strength for the alloy use different heating and holding temperature using controlled cooling rate with different magnetic field strength.

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