Proceedings of CONF-FMCE 2025 Symposium: Semantic Communication for Media Compression and Transmission
DOI: 10.54254/2755-2721/2025.GL24411

Application of Nickel-Based Alloys in Ultra-Supercritical Power Generation: Modification Technology and Performance Optimization

Siyuan Wu

School of Materials & Energy, Lanzhou University, Lanzhou, China
wusy@lzu.edu.cn

Abstract. Coal-fired power generation is dominant in conventional power, but its low efficiency conflicts with carbon neutrality. Ultra-supercritical power plants, operating at high temperatures and pressures with efficiencies near or over 50%, demand strict power generation materials. Nickel-based alloys are commonly employed in such units because of high hardness, good heat and corrosion tolerance, yet lack a review in this field. This paper focuses on their application in ultra-supercritical units, detailing modification methods like elemental doping for wear resistance, physical modification for strength and toughness, and electrochemical modification for machining ease. It also covers characterization means and mechanical property research. This study offers a theoretical basis and technical reference, vital for alloy application and optimization, and power equipment performance improvement.

Keywords: ultra-supercritical generating units, nickel-based alloys, modification methods, characterization means

1. Introduction

In traditional power generation technology, coal-fired power generation occupies an important position and is the mainstream of power generation technology in the world. However, traditional coal-fired power generation units are inefficient and waste a large amount of energy, which is contrary to the current concept of carbon neutrality [1]. However, compared to conventional coal-fired power plants, ultra-supercritical power plants operate at temperatures higher than 700°C, with steam pressures of about 35 MPa, and efficiencies approaching or even exceeding 50% [2]. Operating a generating unit in this specific environment is a huge test for generator materials. In view of this, a single metal is no longer sufficient to meet the demand, and generator components need to be made of alloys with high hardness, excellent heat resistance and strong corrosion resistance.

Among various alloys, nickel-based metals are extensively applied, primarily due to their remarkable mechanical characteristics and exceptional high - temperature oxidation resistance. Among numerous alloy materials, nickel-based materials stand out with their outstanding resistance to high temperatures, remarkable corrosion tolerance, and possess high strength and toughness

© 2025 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2025.GL24411

simultaneously. Wu et al. [3] studied the Cu-15Ni-10Mn alloy to obtain its optimum process parameters: solid solution at 750°C for 2 h, processing rate of 70%, and aging under 400°C for 8 h. At this time, the alloy's tensile strength of 1085 MPa, hardness of 394 HV, and elongation of 1.24%. Gao et al. [4] found that when the addition of Nb to the 0.35%, the as-cast Cu- 9Ni-6Sn alloy has an excellent high temperature resistance and excellent corrosion resistance, as well as high strength and toughness. 9Ni-6Sn alloys were found to have grain refinement from 570 μm to 156 μm when Nb was added to 0.35%, and after aging under 375°C for 1 h, the tensile strength reached 719.5 MPa with an elongation of 13.76%. However, there is no relevant review to summarize the utilization of nickel-based alloys in ultra-supercritical generating units.

This paper conducts an in - depth and comprehensive exploration of the utilization of nickel-based alloys in ultra-supercritical power generation. Considering that the effectiveness of traditional power generation from coal is relatively low, and the ultra-supercritical power generation environment demands high - performance materials, nickel-based alloys distinguish themselves with their outstanding properties. However, various modification methods of nickel-based alloys, including elemental doping, modification by physical methods, and electrochemical modification, have been investigated to better meet the practical needs. In elevating the hardness, wear tolerance, high-temperature tolerance, and machinability of nickel-based alloys, these methods have demonstrated distinctive merits. Different characterization methods and mechanical property tests are also presented to accurately analyze and evaluate the properties of nickel-based alloys.

2. Modification methods for nickel-based material

In order to better apply the nickel-based materials in the ultra-supercritical generating units, the nickel-based materials need to be modified, the main modification methods used include elemental doping, physical modification and electrochemical modification.

2.1. Elemental doping

Doping refers to the technology of introducing trace impurity elements or defects into the base material to change its physical, chemical or electrical properties. Hu et al. [5] doped Ta and C elements into Ni by laser cladding (Figure 1). Ni3Ta-TaC reinforced nickel-based coatings were in-situ synthesized on the substrate. Through comparison, it was evident that the hardness of these coatings had been remarkably enhanced. Moreover, the wear tolerance of the Ni-Ta coatings and the Ni-Ta-C coatings was respectively twofold and fourfold greater than that of 5Cr5MoSiV1 steel. Zhang et al.[6] doped Ti, B, C and other elements onto the surface of 5CrNiMo steel through ultrasonic vibration-assisted laser cladding, which led to the improvement of microhardness and wear resistance of the coatings, the reduction of the coefficient of friction, as well as ultrasonic vibration-induced grain refinement and uniform distribution of enhanced phases, leading to harder coatings; Cr is able to generate a compact and stable surface oxide film of the base material. This not only enhances the hardness of the substrate but also boosts its wear tolerance. Additionally, Cr2O3 contributes to enhancing the anti-oxidation capability at high temperatures of the substrate, as reported by Zhang et al. [7] doped W, C and other elements (in the form of WO3, graphite and other powder mixing) to the surface of 45# steel through the laser cladding method, the cladding layer organization is uniform and dense, no cracks and holes and other defects, and the substrate is a good metallurgical combination, the microhardness of the coating can reach up to 900 HV0.2. Ning et al. [8] doped V, W, C and other elements (in the form of V2O5, WO3, graphite powder and Ni60 mixed powder) onto the surface of 45 steel by laser cladding technology, the surface of the cladding

DOI: 10.54254/2755-2721/2025.GL24411

layer is smooth with good morphology, no small depression with very high hardness and an average of 1400 HV0.3, and the in situ generation of VC-WxC/Ni cladding layer of the abrasion resistance is 6 times of that of the pure Ni60 coating. The laser cladding method has good metallurgical bonding, precise control, and extensive applications, but the thickness of the cladding layer is limited, and for application scenarios that require thick coatings, multiple claddings are required.

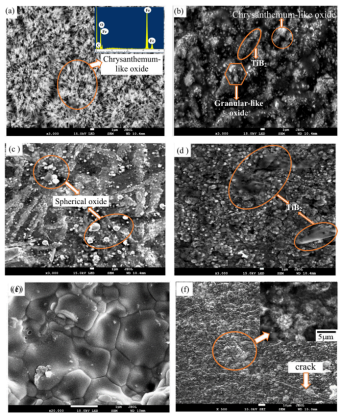


Figure 1: Microstructure of the substrate and coatings after oxidation: (a) substrate; (b) coating without UV; (c) coating with 300 W UV; (d) coating with 400 W UV; (e) enlarged image of the matrix for the S3 coating; (f) oxidized morphology near the crack in the S4 coating [6]

2.2. Physical modification

Physical modification refers to the process of applying physical means to change the properties of a material to make it have better performance or be more suitable for a specific purpose. In materials science, common means of physical modification include laser cladding, electron beam bombardment, and solid solution strengthening, etc., which are employed to enhance the characteristics of materials, including strength, toughness, heat resistance, and corrosion resistance.

Cheng et al. [9] experimented with laser cladding by using the synchronized powder feeding method, which is highly efficient, produces a uniform cladding layer and also reduces metal oxidation. The laser power was 1800 W, the scan velocity was 0.012 m/s, Ar gas protection was used, and the microhardness test and friction wear test were performed on the alloy after grinding, polishing, and etching, and it was observed the microhardness, on average, of the fused cladding layer was notably improved (Figure 2), and the average microhardness value of the melted cladding layer reached 620.52 HV0.5 when the content of Y2O3 was 0.8%, which is compared to that of the fused cladding layer without added The average microhardness of the fusion-coated layer reached 620.52 HV0.5 when the Y2O3 content was 0.8%, which was 1.35 times higher than that without the addition of rare-earth oxides, and the mass loss during friction was the smallest, indicating that the wear-resistant performance was the best at this time. When the CeO2 content was 0.4%, the microhardness, on average, of the fused cladding layer reached 730.76 HV0.5, which was enhanced 1.59 times compared with that when no rare earth oxides were added. Li et al. [10] used a SEBW80KV/12KW vacuum electron beam welder operating at an hastening voltage of 60 kV and a scanning speed of 0.24 m/min to surface modify Inconel 625 nickel-based alloys using ring scanning. The method employs an electron beam with high energy density, which is capable of melting and welding the material quickly, and can precisely control the beam current to realize high-quality welding. Tests were carried out using a reciprocating sliding module, and characterization of

DOI: 10.54254/2755-2721/2025.GL24411

the specimens revealed that the hardness of the Inconel 625 alloy after electron beam scanning was increased, and the surface roughness, wear volume and wear rate were significantly reduced, with the wear volume being minimized to 0.141525 mm3, a reduction of 26.64% in comparison to the substrate after the 720 mA electron beam scanning treatment. The electron beam's high energy density used in this method can melt and weld the material quickly, and can precisely control the beam current to realize high-quality welding, but there are some physical phenomena affecting the processing quality, such as the balling phenomenon which will hinder the formation of a continuous molten pool and lead to surface roughness.

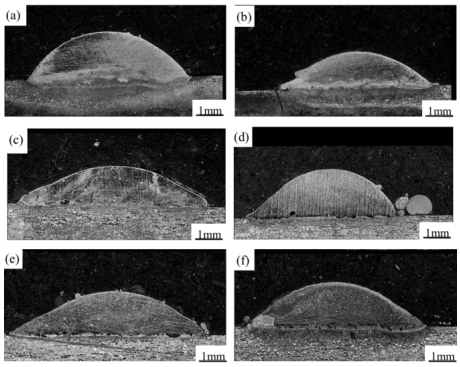


Figure 2: Macroscopic morphology of fused cladding layer with different Y2O3 content [9]

Giridhar Gudivada [11] et al. optimized the microstructure of the alloy by adding rare earth elements and refractory metal elements (e.g., rhenium, ruthenium, neodymium, etc.) by using solid solution and aging treatments to improve the solid solution strengthening and precipitation strengthening of the alloy (Figure 3). By solid solution strengthening, IN 718 alloy achieves a yield strength of 860-1090 MPa and a microhardness of about 600 HV at 650°C. By precipitation strengthening, CMSX-4 single-crystal alloy achieves a yield strength of about 900 MPa and a microhardness of about 650 HV at 800°C. The phase and chemical microsegregation formed by non-isothermal solidification were eliminated by a multi-step heat treatment process, and experimental results were obtained. chemical micro-segregation, the experimentally obtained γ' phase of nickel-based alloys is fine and uniformly distributed, and the tensile strength and creep behavior at high temperatures are significantly improved, e.g., the creep life of CMSX-4 alloy is longer than that of conventional alloys at 850°C. The creep life of CMSX-4 alloy is longer than that of conventional alloys. The laser fusion cladding layer of GH4169 alloy with 0.8% Y2O3 added, the average microhardness reaches 620.52 HV0.5, which is 1.35 times higher than that of the unadded rare-earth oxides, while the fusion cladding layer with 0.4% CeO2 added reaches 730.76 HV0.5, which is 1.59 times higher than that of the unadded one. Both solution annealing and age hardening can enhance the strength and hardness and refine the fatigue resistance and stability, but it is necessary to determine the appropriate parameters, otherwise it will lead to the deterioration of the performance.

DOI: 10.54254/2755-2721/2025.GL24411

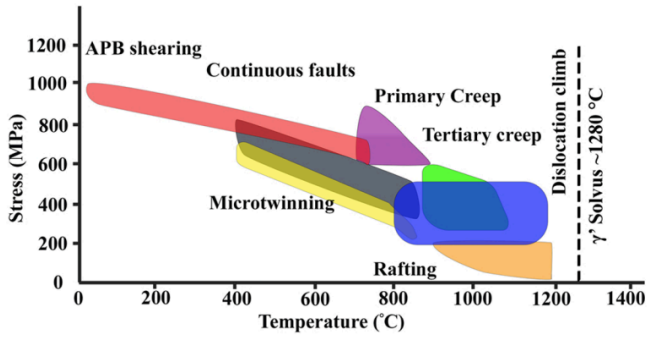


Figure 3: Effect of temperature and pressure on mechanical properties of single crystal alloys [11]

2.3. Electrochemical modification

Electrochemical modification is a method of changing the properties of a material through electrochemical reaction, so as to make it have better performance or be more suitable for specific purposes. In the field of materials science, electrochemical technology finds extensive application in surface treatment, modification and performance optimization of materials, and common means include electroplating, electrochemical corrosion, anodic oxidation, etc., which are used to enhance the corrosion resistance, hardness, surface roughness, decorative and other properties of materials.

Shi et al. [12] successfully modified the surface of the nickel-based high temperature alloy K417G by electrochemical selective dissolution technique, selecting NaCl as the neutral electrolyte, and electrochemically corroding the alloy K417G for 600 s at a potential of 2.0 V vs SCE in a 15 wt% NaCl electrolyte, removing the γ' phase of the surface layer (Figure 4), forming a porous modified layer with low hardness. This modification significantly reduced the machining difficulty of the alloy while maintaining the characteristics in high temperature conditions of the material. Wang[13] and others treated Inconel 718 nickel-based alloy using a mixture of $NaNO_3$ and NaOH, and the non-machined surfaces formed a dense passivation film to protect the base material from corrosion, which significantly improved the positioning effect of electrochemical machining (ECM).After modification, the non-machined surface roughness of the alloy was reduced remarkably, and the average roughness Ra reduced from 2.34 μm to 1.48 μm.

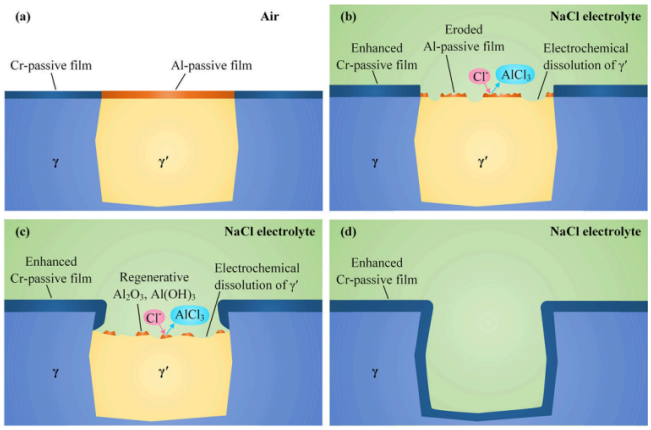


Figure 4: Schematic diagram of γ′-electrochemical selective dissolution [12]

DOI: 10.54254/2755-2721/2025.GL24411

Wu et al. [14] achieved selective dissolution of γ substrate by electrochemical reaction in $C_6H_5Na_3O_7$ solution (Figure 5). Cr^{3+} ions formed water-soluble complexes with Cit^{3-}, which resulted in the Cr_2O_3 passivation film becoming loose and porous. This was followed by electrochemical treatment at low current densities to avoid spalling of the modified layer. The current densities used in the experiments ranged from 0.2 to 1.4 A/cm² and the treatment time was 180 seconds. After the modification, a loose and porous altered layer was created on the surface of GH4742, featuring a smooth surface and an evenly distributed depth, while the hardness feature of the treated layer was significantly decreased from 402.12 HV0.01 of the substrate to 11.55 HV0.01. This method of electrochemical surface modification provides an effective means of pre-treatment for machining of GH4742 nickel-base alloy, which can remarkably enhance the machining performance and lay a solid basis for the following precision machining. However, for multiphase materials with complex chemical composition, the electrochemical dissolving of every phase during electrochemical machining is not uniform, and the machined surface is prone to severe flaws such as deep localized erosion pits and crevices, which makes it difficult to ensure the machining stability and machining accuracy.

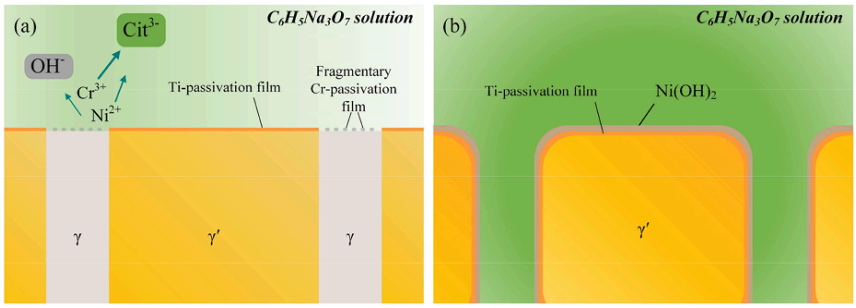


Figure 5: Schematic model of electrochemical modification mechanism [14]

3. Characterization methods

At present, the main means of characterization in materials science research are scanning electron microscopy, transmission electron microscopy, X-ray diffraction and thermal analysis, etc. These methods can be used to analyze all aspects of materials with high precision.

Topographic characterization refers to the process of observing, measuring and analyzing the surface morphology, microstructure and physical properties of a material or sample. In materials science, topographic characterization can help researchers understand the surface features, crystal structure, defect distribution and other information of materials, which are important for the optimization of material properties and application development. For example, the roughness, particle size, porosity, etc. of a material's surface can be observed through topographic characterization, which can be used to evaluate the material's properties such as abrasion resistance, corrosion resistance, catalytic activity, and so on.

Currently, the main instruments used for characterization are scanning electron microscopy (SEM), transmission electron microscopy (TEM), atomic force microscopy (AFM), X-ray diffraction (XRD), scanning probe microscopy (SPM), and focused ion beam (FIB). Of these, scanning electron microscopy has particularly broad applications. Scanning electron microscopy functions by emitting a stream of high-energy electrons onto the exterior of a sample, which is focused into a very small spot by an electromagnetic lens and scans the exterior of the sample. The

DOI: 10.54254/2755-2721/2025.GL24411

electron stream engages with the surface of the sample and gives rise to signals like secondary electrons and backscattered electrons. These signals are received by a detector and processed by a computer system, resulting in a crisp image of the sample surface [15].

Sun[15] observed the γ′ phase precipitation of nickel-based alloy U720Li at different temperatures and strains (650°C/0.8%, 650°C/1.0%, 650°C/1.2%, 725°C/0.8%, 725°C/1.0%, 725°C/1.2%) after low-cycle fatigue (LCF) testing by TEM dark-field imaging and found that dislocations in the intracrystalline slip and interact with the γ′ phase (especially the primary γ′ phase) (Figure 7). At lower strains, the dislocations concentrate to form dislocation walls and act as subgrain boundaries; at higher strains, the dislocation density increases and the dislocation configuration shifts from stacking at the interface of the substrate or primary γ′ -phase precipitation to penetrating through the primary γ′ -phase precipitation, because the concentration of stress at the boundary induces the dislocations to overcome the energy barriers to slip further. Shashi Ranjan Singh et al. [16] observed the dislocations to slip within a grain and interact with the γ′ phase (especially primary γ′-phase precipitation) in pristine state (ASR) samples by TEM. In the samples, it was observed by TEM that γ' and γ" precipitated inside the grains and δ phase precipitated at the interfaces of grainsz; after solid solution treatment (SHT), only the γ matrix phase existed in the samples; after different aging treatments, different morphologies and distributions of precipitated phases appeared again, e.g., after 600°C/8h aging treatment, there was the δ phase precipitated inside the grains in the form of a long parallel lamellar shape.

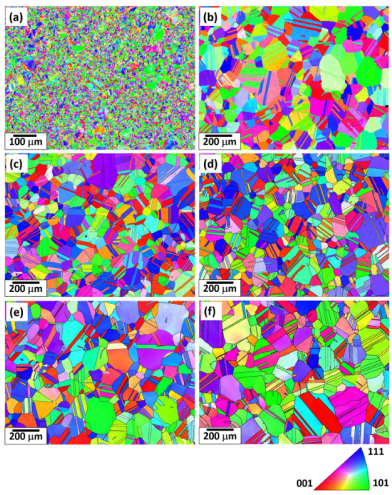


Figure 6: Inverse Pole Figure (IPF) map of (a) As received inconel-718 (b) Solutionized at 1040°C/1 h, WQ (c) Aged at 600 ◦ C/8 h (d) Aged at 750 ◦ C/3 h (e) Aged at 750 ◦ /8 h (f) Aged at 850 °C/8 h [15]

Zhang et al. [17] carried out in-situ tensile experiments on the fourth-generation nickel-based single-crystal high-temperature alloys at room temperature and 700 °C, and observed the slip traces on the surface of the samples in real time by SEM at different strains. As shown in Figure 6, at room temperature, the slip markings produced by the predominant slip system SS1 were mainly observed in the OA sample at 22.8% strain; the slip markings generated by SS2 and SS4 appeared in the OB sample at 17.5% strain; the slip traces generated by four slip systems, namely, SS1, SS2, SS4, and SS7, were observed in the OC sample at 14.3% strain; and at 700°C, the slip markings created by the chief slip system were mainly observed in all oriented samples. Zhou et al. [18] observed the fatigue crack initiation process of nickel-based single-crystal alloys at 950°C promptly by in-situ SEM, and

DOI: 10.54254/2755-2721/2025.GL24411

found that when loaded up to 16 cycles, slip traces appeared on the right side of the specimen notch; when loaded up to 30 cycles, a large number of microcracks were aligned along the slip lines and tore the γ and γ' phases; when loaded up to 55 cycles, initial microcracks were observed and the γ and γ' phases were torn; and the γ and γ' phases were torn. At 55 cycles, the initial microcracks were observed with a length of 10.63 μm; at 61 cycles, the original crack length reached 18.93 μm and secondary cracks appeared.

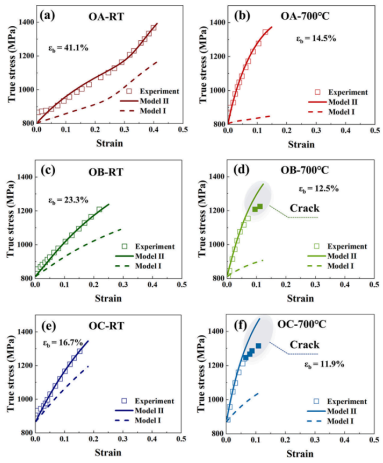


Figure 7: Comparison of experimental and simulated stress-strain response curves [18]

Physical properties related to mechanics of the material is an crucial standard to measure the material performance indicators, including tensile strength, microhardness and so on. Wei et al. [19] used a two-step diffusion coupling technique to prepare end-element alloys by selecting Ni, Ti, Al and Cr raw materials with high purity, and melting them several times in an electric arc melting furnace under argon gas protection. As shown in Figure 8, when adding Al elements to Ni56Ti44 alloy and the content is lower than 5.0at%, the hardness of the alloy has a tendency to augment, and the Young's modulus of Ni56Ti44-Al alloy fluctuates around 130 GPa; Ni56Ti44-Al alloy containing 2.8at% of Al, the hardness is up to 11.3 GPa, which exceeds that of the binary alloy of Ni56Ti44, which is 8.0 GPa.When Cr was added to Ni56Ti44 alloy and the content was lower than 1.8at%, the Young's modulus of the alloy was at the same level as that of 60NiTi alloy, and the hardness of Ni56Ti44-Cr alloy increased with the growth of Cr quantity, and the rigidness of the alloy containing 1.7at% of Cr could reach 9.6 GPa. Wang et al. [20] mixed Al powder, Ni powder and CuO powder by ball milling at 120 rpm for 60 min at ambient temperature, and then hot pressed and moulded at 400°C and 230 MPa for 4 h. 3 mm and 6 mm thick sheet were made, and the micro hardness of FSAM zone was evaluated via a micro Vickers indenter under a burden of 500 g and a holding time for 10 s. The rigidness of the alloys in the FSAM zone was evaluated via a micro Vickers indenter with a holding time of 10 s. The rigidness of the alloys in the FSAM zone was measured using a micro Vickers indenter. The strength in compression of Al/Ni ESM in hot-pressed state was 160 MPa and that of Al/Ni ESM prepared by FSAM was 261 MPa when no CuO was added. The strength in compression of heat - pressed region showed a decreasing trend with the elevation of CuO concentration from 0 to 15 wt%, and the strength in compression of Al/Ni ESM prepared by FSAM revealed an obvious increasing trend, when the CuO content reached15 wt%, 394 MPa is reached by the strength in compression.

DOI: 10.54254/2755-2721/2025.GL24411

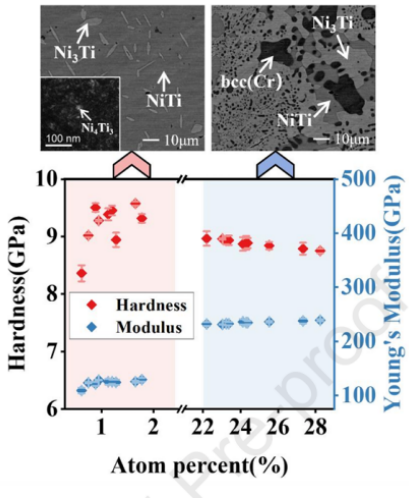


Figure 8: Average hardness ($\bar{H}$) and Young's modulus ($\bar{E}$)-composition profiles of Ni56Ti44-Ni56Ti22Cr22 two-step diffusion couple [20]

Tu et al. [21] used DD6, being a second - generation nickel - based single - crystal alloy, which was processed into tubular specimens after standard heat treatment, and performed TMF tests on an Instron 8801 hydraulic servo fatigue tester to test the in-phase (IP) and out-of-phase (OP) TMF performance at different stress levels and visualise the data (Figure 9). In IP-TMF, the specimen is at a higher temperature during the tensile stage, and as the stress and temperature increase, the tensile strength of the material decreases, the modulus of elasticity decreases, and the strain accelerates as the stress increases, which is due to the fact that the high temperature weakens the capabilities of the material to resist distortion, and makes the material more susceptible to plastic deformation; whereas, when the temperature decreases and the stress is unloaded, the strain rate decreases, and the curve exhibits downward curvature, which is due to the fact that the material is in thecooling process, the internal structure is gradually restored and the ability to resist deformation is enhanced, resulting in a slowdown of the strain change, reflecting the partial reversibility of the elastic recovery and plastic deformation of the material.Similarly, in OP-TMF, the specimen bears the maximum stress under low-temperature conditions, and with the increase of mechanical load and the decrease of temperature, the tensile resistance and modulus of elasticity of the material increase, and the initial stage of the curve shows cyclic hardening, and then enters into cyclic stable state, reflecting the material gradually adapts to the load under high stress at low temperature, and the organisational structure undergoes the adjustment of the resistance to deformation; when the mechanical loading attains its maximum value and the temperature decreases to the minimum level after theinto the heating and unloading stage, the material is softened by heat, and the relationship curve between stress and strain shows upward bend in the hysteresis loop, indicating that the material resistance to deformation decreases and more plastic deformation occurs during heating.

DOI: 10.54254/2755-2721/2025.GL24411

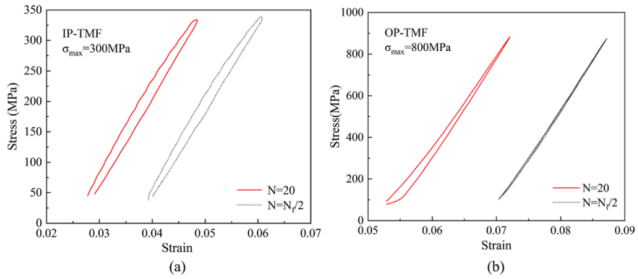


Figure 9: Comparison of cycling behavior under different stress conditions:(a) IP-TMF stress-strain curves (stress 300 MPa); (b) OP-TMF stress-strain curves (stress 800 MPa) [21]

4. Conclusion and outlook

Nickel-based alloys have become an ideal material choice for ultra-supercritical generator set components because of their outstanding mechanical properties, high-temperature oxidation tolerance, and the ability to high-temperature and corrosion resistance. In the ultra-supercritical power generation environment, the performance advantages of nickel-based alloys help to improve the power generation efficiency and adapt to the high temperature and high pressure working conditions.Elemental doping can substantially boost the wear resistance of the material, such as laser cladding doping Ta, C elements can make nickel-based coatings wear resistance increased significantly; physical methods of modification, such as laser cladding, electron beam bombardment, solid solution strengthening, etc., to optimise the strength, toughness and other properties of the material; electrochemical modification reduces the difficulty of machining, and improves the machining accuracy. At the same time, scanning electron microscopy, transmission electron microscopy and other means of characterisation provide an efficient approach to accurately analyse the characteristics of nickel-based alloys, and have yielded rich results in the study of the mechanical characteristics of nickel-based alloys. Although the current modification methods of nickel-based alloys have achieved certain results, the microscopic mechanism of the modification process has not been fully clarified, and further in-depth studies on the changing law of the atomic scale in the process of elemental doping, physical and electrochemical modification, and how these changes affect the macroscopic properties of the alloys are needed in the future to provide theoretical basis for more accurate optimisation of the modification process.

References

[1] Zhou G B, Bian S, Chen Z Y, et al. Experimental study on high-temperature low-week fatigue performance of Inconel 617 and C-HRA-2 alloys for advanced ultra-supercritical units[J]. Journal of Power Engineering, 2022,42(05):475-483.
[2] Zhang X L, Modification and characterisation of nickel-based alloy materials for ultra-supercritical power generation[J]. Journal of Physics: Conference Series, 2808 (2024) 012005.
[3] Wu Y, Study on the organization and properties of Cu-15Ni-10Mn alloy. Jiangxi University of Science and Technology, 2012.
[4] Gao M Q, Chen Z N, Kang H J, et al. Materials Science and Engineering: A, 2018, 715 340.
[5] Hu D W, Liu Y, Chen H, et al. Microstructure and properties of in-situ synthesized Ni3Ta-TaC reinforced Ni-based coatings by laser cladding[J]. Surface and Coatings Technology, 2020, 405: 126599.
[6] Zhang M, Zhao G L, Wang X H, et al. Microstructure evolution and properties of in-situ ceramic particles reinforced Fe-based composite coating produced by ultrasonic vibration assisted laser cladding processing[J]. Surface and Coatings Technology, 2020, 403: 126445.

DOI: 10.54254/2755-2721/2025.GL24411

[7] Zhang Y M, Shuai G G, Huang J H, et al. Laser cladding of in situ autogenous WxC particles reinforced nickel-based composite coatings[J]. Metal Heat Treatment, 2016, 41(2): 79-83.
[8] Yang N, Li L K, Chao M J. In situ growth of VC-WxC particle-enhanced nickel-based coatings by laser cladding[J]. Laser Technology, 2012, 36(5): 627-631.
[9] Cheng P Y. Research on the organization and properties of laser repaired brass structural parts with rare earth oxide modified nickel-based alloy[D]. Nanchang University of Aeronautics and Astronautics,2022.
[10] Zhao L, Dong A F, Yao J Y, et al. Research on the organization and friction properties of nickel-based alloys modified by electron beam surface modification[J]. Weapon Materials Science and Engineering,2023,46(05):34-40.
[11] Gudivada G, Pandey A K. Recent developments in nickel-based superalloys for gas turbine applications[J]. Journal of Alloys and Compounds, 2023, 963: 171128.
[12] Shi X, Niu L, Yang G, et al. Surface modification of nickel-based superalloy by electrochemical selective dissolution[J]. Journal of Alloys and Compounds, 2023, 947: 169628.
[13] Wang D, He B, Cao W. Enhancement of the localization effect during electrochemical machining of inconel 718 by using an alkaline solution[J]. Applied Sciences, 2019, 9(4): 690.
[14] Wu F, Tong H, Chen F, et al. Electrochemical surface modification of GH4742 nickel-based superalloy in C6H5Na3O7 solution[J]. Surfaces and Interfaces, 2024, 45: 103815.
[15] Sun F. Integrated TEM/transmission-EBSD for recrystallization analysis in nickel-based disc superalloy[J]. Progress in Natural Science: Materials International, 2021, 31(1): 63-67.
[16] Singh S R, Mote R G, Mishra S K. The effect of microstructures and precipitates (γ', γ ″, δ) on machinability of Inconel-718 nickel-based superalloy in turning process[J]. Journal of Manufacturing Processes, 2022, 82: 374-389.
[17] Zhang W, Chen S, Guo G, et al. Study on plastic deformation mechanism of a fourth-generation nickel-based single crystal superalloy: In-situ SEM characterization and dislocation density-based model[J]. Materials Science and Engineering: A, 2025, 930: 148132.
[18] Zhou J, Gao W, Liu L, et al. In-situ SEM study on fatigue crack behavior of a nickel-based single crystal alloy at 950° C and 1050° C[J]. Materials Characterization, 2023, 199: 112763.
[19] Wei Y, Chen S, Jin Y, et al. Effect of Al/Cr addition on microstructure and mechanical properties of Ni-rich nitinol alloys[J]. Journal of Materials Research and Technology, 2025.
[20] Wang M, Zhu S, Wang T, et al. Influence of CuO addition on the microstructure, exothermic characteristics and mechanical properties of Al/Ni/CuO energetic structural materials prepared by friction stir additive manufacturing[J]. Journal of Materials Research and Technology, 2025, 35: 6537-6550.
[21] Tu Y, Wang J, Wen Z, et al. Thermomechanical Fatigue Behavior and Lifetime Prediction of Nickel-Based Single Crystal Alloys Under Varying Stress Conditions[J]. Journal of Alloys and Compounds, 2025: 180202.