

A REVIEW ON RESEARCH TREND IN CORROSION RESISTANT ALLOY (HASTELLOY)

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ABSTRACT

The Corrosion-Resistant HASTELLOY alloys are widely used by the chemical processing industries. The need for reliable performance leads to their acceptance and growth in the areas of energy, health and environmental, oil and gas, pharmaceutical and flue gas desulfurization industries. The attributes of HASTELLOY alloys include high resistance to uniform attack, outstanding localized corrosion resistance, excellent stress corrosion cracking resistance, and ease of welding and fabrication. HASTELLOY fasteners, such as HASTELLOY C276 fasteners, are made from nickel-molybdenum-chromium alloy that is generally considered a versatile highly corrosion resistive alloy. HASTELLOY fasteners have excellent corrosion resistance in both oxidizing and reducing media which makes it well suited for a variety of strong corrosive applications. HASTELLOY fasteners also have exceptional resistance to both sulfuric acid and hydrochloric acid. The paper review and research trends carryout regarding HASTELLOY alloys including the further scope for its research so as to utilize it further and improve its machinability.

Keywords : *Hastelloy, Corrosion resistive alloy, Metallurgy, Machining.*

I. INTRODUCTION

Hastelloy is a series of high-strength, nickel based, corrosion resistant alloys. Alloys of identical chemical and mechanical properties are available from other manufacturers and offer excellent alternatives to the various Hastelloy alloys. Other components of the alloys include molybdenum and chromium. These alloys are well suited for most chemical applications. They have excellent resistance to pitting, stress-corrosion cracking and to oxidizing atmospheres up to 1900 °F.

1.1-General Properties Of Hastelloy

Density	8.89 gm/cm ³
Specific Heat:	427 °C
Melting Point Range:	1325-1370 °C
Thermal Conductivity:	9.8 W/M-k
Electrical Resistivity:	1300
Coefficient of Thermal Expansion:	11.2 um/M-k

1.2-Typical Analyses - Chemical Composition

Material / Purity (%):	C-276	C-22
Ni	57.0	56.0
Co	2.50	2.50
Cr	15.5	22.0
Mo	16.0	13.0
W	4.00	3.00
Fe	5.50	3.00
Si	0.080	0.080
Mn	1.000	0.500
P	0.025	0.010
S	0.010	0.020
V	0.350	0.350

1.3-HASTELLOY Family Of Corrosion-Resistant Alloys

<u>HASTELLOY B-3 alloy</u>	Same excellent resistance to hydrochloric acid and other strongly reducing chemicals as B-2 alloy, but with significantly better thermal stability, fabricability and stress corrosion cracking resistance.
<u>HASTELLOY HYBRID- BC1 alloy</u>	A new Ni-Cr-Mo alloy with superior resistance to hydrochloric and sulfuric acids, without the drawbacks of the Ni-Mo and Zr materials. Its resistance to these key chemicals is much greater than that of the popular Ni-Cr-Mo (C-type) alloys, yet it shares with them the outstanding resistance to pitting and crevice attack in chloride salt solutions, and even withstands high levels of oxidizing impurities that the Ni-Mo alloys cannot cope with.
<u>HASTELLOY C-4 alloy</u>	High-temperature stability in the 1200-1900°F (650-1040°C) range as evidenced by good ductility and corrosion resistance. Virtually the same corrosion resistance as alloy C-276.
<u>HASTELLOY C-22 alloy</u>	Better overall corrosion resistance in oxidizing corrosives than C-4, C-276 and 625 alloys. Outstanding resistance to localized corrosion and excellent resistance to stress corrosion cracking. Best alloy to use as universal weld filler metal to resist corrosion of weldments.
<u>HASTELLOY C-22HS alloy</u>	This alloys was designed to exhibit corrosion resistance comparable to other C-type alloys, but which can be heat treated to obtain approximately double the yield strength.
<u>HASTELLOY C-276 alloy</u>	Versatile, corrosion resistant alloy. Very good resistance to reducing, and mildly oxidizing corrosives. Excellent stress corrosion cracking resistance with very good resistance to localized attack.
<u>HASTELLOY C-</u>	Most versatile, corrosion resistant alloy with excellent resistance to uniform corrosion in

<u>2000 alloy</u>	oxidizing or re-reducing environments. Excellent resistance to stress corrosion cracking and superior resistance to localized corrosion as compared to C-276 alloy.
<u>HASTELLOY G-30 alloy</u>	Many advantages over other metallic and non-metallic materials in handling phosphoric acid, sulfuric acid, nitric acid, fluoride environments and oxidizing acid mixtures.
<u>HASTELLOY G-35 alloy</u>	Excellent resistance to corrosion in highly oxidizing media and acidic chloride environments.
<u>HASTELLOY N alloy</u>	Good resistance to aging and embrittlement and good fabricability. It has excellent resistance to hot fluoride salts in the temperature range of 1300°F to 1600°F (705°C-870°C).

1.4-Corrosion-Wear Resistant Alloy

<u>ULTIMET alloy</u>	High yield strength alloy with excellent resistance to pitting corrosion and general corrosion, especially in oxidizing acids, coupled with exceptional wear resistance (cavitation erosion, galling and abrasion).
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1.5-Fabrication of HASTELLOY Corrosion-Resistant alloys

<u>Fabrication of HASTELLOY Corrosion-Resistant alloys</u>	General Guidelines for Welding, Brazing, Hot and Cold Working, Heat Treating, Pickling and Finishing.
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1.6-Application of HASTELLOY

Flue gas scrubbers, Chlorination systems, Acid production and pickling systems, Outlet ducting and stack liners for power plants, Sulfur dioxide scrubbers, Fasteners, Pulp and paper bleach plants, Weld overlay of less corrosion resistant metals, Pesticide and other agricultural production, Tubular heat exchangers, Plate heat exchangers, Nuclear fuel reprocessing and Nuclear Submarine turbine blades and Incineration scrubber systems etc.

II. RESEARCH AND DEVELOPMENT

- **M. J. Cieslak, T. J. Headley, A. D. Romig (1)** described the welding metallurgy (solidification and solid state transformations) of HASTELLOY* Alloys C-4, C-22, and C-276. Varcstraint hot-cracking tests performed on commercial alloys revealed a weldability ranking as follows: C-4 > C-22 > C-276. All alloys would be expected to have good weldability, with Alloy C-4 having a very low hot-cracking tendency, comparable to 304L stainless steel. Microstructures of gas-tungsten-arc welds of these alloys have been characterized by scanning electron microscopy and analytical electron microscopy. Intermetallic secondary

solidification constituents have been found associated with weld metal hot cracks in Alloys C-276 and C-22. In Alloy C-276, this constituent is a combination of P and ω phases, and in Alloy C-22, this constituent is composed of σ , P , and ω phases. With phase composition data obtained by AEM techniques and available ternary (Ni-Cr-Mo) phase diagrams, an equivalent chemistry model is proposed to account for the microstructures observed in each alloy's weld metal.

- **M. Raghavan , B. J. Berkowitz , J. C. Scanlon (2)** observed three distinct second phases form heterogeneously at grain and deformation twin boundaries when Hastelloy C-276 was aged in the temperature range of 923 to 1173 K. The most abundant was the faulted, molybdenum rich μ phase. The next most abundant phase was molybdenum rich M_6C carbides, and the third phase, which was observed very infrequently, was tentatively identified as the P phase. The compositions of these phases were remarkably similar, and the need to employ several electron microscopy techniques is emphasized. The origin of the μ phase is discussed in the light of its chemistry.
- **Qiang Zhang, Rui Tang Kaiju Yin ,Xin Luo, Lefu Zhang (3)** investigated the corrosion behavior of a nickel-based alloy Hastelloy C-276 exposed in supercritical water at 500–600 °C/25 MPa means of gravimetry, scanning electron microscopy/energy dispersive X-ray spectroscopy, X-ray diffraction and X-ray photoelectron spectroscopy. An oxide scale with dual-layer structure, mainly consisting of an outer NiO layer and an inner $Cr_2O_3/NiCr_2O_4$ -mixed layer, developed on C-276 after 1000 h exposure. Higher temperature promoted oxidation, resulting in thicker oxide scale, larger weight gain and stronger tendency of oxide spallation. The oxide growth mechanism in SCW seems to be similar to that in high temperature water vapor, namely solid-state growth mechanism.
- **J. Lu, E. S. Choi, and H. D. Zhou (4)** described the Ni–Mo–Cr superalloy Hastelloy® C-276™ has been used as a substrate material for fabricating superconducting tapes such as YBCO and MgB₂ coated conductors. With increasing piece length, these coated conductors are within reach of large scale commercial applications. However, data on the physical properties of Hastelloy C-276 at temperatures relevant for these applications are not yet available. In this work, physical properties including magnet susceptibility, specific heat, electrical resistivity, and the Seebeck coefficient are measured from 2 to 300 K and thermal conductivity from 2 to 200 K. the result that Hastelloy C-276 exhibits Curie paramagnetism between 4 and 300 K with a Curie constant $C=0.091$ K. A spin-glass-like behavior is observed below 3 K. The electrical resistivity has a minimum at ~ 12 K, and shows a linear weak T dependence at higher temperatures. The specific heat C_p between 15 and 40 K follows $C_p = \gamma T + AT^3$. Below ~ 10 K, an upturn in C_p/T with decreasing T is interpreted by the existence of very small ferromagnetic clusters.
- **J.I. Akhter a , M. Akhtar a , M. Iqbal a , E. Ahmed a , M.A. Choudhry (5)** described electron beam welding (EBW) technique is becoming popular in nuclear, chemical and aerospace industries due to its high penetration depth and fast cooling rate. Samples of Hastelloy C-276 have been welded by electron beam (EB). A scanning electron microscope (SEM) having the attachment of an energy dispersive system (EDS) has been employed to study the resulting microstructure and micro-eutectic phases. The microstructure of the molten zone (MZ) is found to be of fine lamellar type. The hardness of the MZ is found to be 35% higher compared to as-received alloy. The micro-eutectoids are rich in Mo and W. The X-ray diffraction patterns of the MZ show shifting of peaks towards higher angle compared to the diffraction pattern of the

as-received alloy. Broadening of the peaks is also observed in the diffraction pattern of the MZ. Formation of the μ -phase was observed in the MZ after a tempering treatment at 950 °C.

- **J. C. Villegas a , L. L. Shaw a* , K. Dai a , W. Yuan b , J. Tian b , P. K. Liaw b & D. L. Klarstrom (6)** described improvements in the fatigue resistance of a nickel-based alloy have been achieved via a surface nanocrystallization and hardening (SNH) process. The enhanced fatigue resistance is related to the surface nanocrystallization, work hardening, and compressive residual stresses induced by the SNH process.
- **R. V. Miner , M. G. Castelli (7)** described isothermal cyclic deformation tests were conducted on HASTELLOY X with a total strain range of ± 0.3 pct at several temperatures and strain rates. Cyclic hardening exhibited a broad peak between about 200 °C and 700 °C, with a maximum near 500 °C of about 80 pct increase in stress amplitude, $\Delta\sigma/2$, at failure. The present work examines the mechanisms contributing to this marked cyclic hardening. Cr 23 C 6 precipitation on dislocations contributed to hardening, but only with sufficient time above about 500 °C. The substantial hardening rate at lower temperatures or shorter times was attributed to solute drag. The contribution of solute drag was evidenced in tests at both 400 °C and 600 °C by a continually decreasing strain rate sensitivity of the AcrJ2.
- **J.-C Zhao, M Larsen, V Ravikumar (8)** described transmission electron microscopy (TEM) was employed to study the phase precipitation in Hastelloy X heat-treated at 750, 850, and 900°C for 26 and 100 h. Phase identification was made by electron micro-diffraction and energy dispersion spectroscopy (EDS) X-ray micro-chemical analysis. In addition to the fcc matrix, four different precipitation phases were observed: M 6 C, M 23 C 6 , σ , and μ . The current observations were combined with literature results to build a time–temperature–transformation (TTT) diagram for this alloy. This TTT diagram depicted time–temperature regimes where various phases were formed; thus, it provided information about the general precipitation kinetics for the alloy.
- **Woo-Gon Kim, Song-Nan Yin, Yong-Wan Kim, Jong-Hwa Chang(9)** investigated the θ projection method was applied to characterize the creep behavior of the Hastelloy-X alloy at 950 °C. Four θ parameters were established by a nonlinear least square fitting (NLSF) to the creep curves. In the NLSF of the full creep curves, the $\theta 1$ and $\theta 2$ parameters were not defined with a large error, but the $\theta 3$ and $\theta 4$ parameters were defined well without an error. An optimum cutoff strain range for defining the four θ parameters was found to be a 3% strain. Four θ parameters revealed a good linearity as a function of stress. The predicted minimum creep rate showed a good agreement with the experimental data. At 950 °C of the Hastelloy-X alloy, the creep curves, the creep rate, and the time to reach a limiting strain were estimated with a wide range of stresses.
- **Fude Wang (10)** studied the tensile mechanical properties of selective laser-melted Hastelloy® X alloy in as-deposited condition and after hot isostatic pressing (HIP) at ambient and elevated temperatures. Room temperature four-point bending and tension–tension fatigue properties have also been investigated in as-deposited condition and after HIP. The yield strength of the as-deposited selective laser-melted Hastelloy® X specimen is higher than the heat-treated (hot forged) samples. The ultimate strength is also higher than that of the hot forged samples while the elongation property is lower. This can be attributed to its ultrafine microstructure caused by rapid solidification, which is characteristic of the selective laser melting process.

It is also found that the mechanical properties (tensile and fatigue) do not vary with samples built in different bed locations.

- **R. B. LEONARD (11)** define the Hastelloy Alloy C has long been of major importance to the chemical process industry, but in many applications, vessels fabricated from Alloy C had to be solution heat treated to remove harmful weld heat affected zone precipitates which reduced corrosion resistance. Modification of the chemical composition produced Hastelloy Alloy C-276, which is more resistant to the precipitation of grain boundary particles than Alloy C. In order to fully utilize the improved alloy, and to understand its responses to fabrication techniques, it is helpful to understand the time-temperature-transformation characteristics. Grain boundary precipitates can form in Alloy C-276 when it is exposed to temperatures from 1200 to 2000 F (649 to 1093 C). The precipitation characteristics of Alloy C-276 compared to those of Alloy C can be shown through the use of a time-temperature-transformation curve (T-T-T). The precipitates have been identified as either “P” or Ni 7 Mo 6-type phases. No M 6 C precipitate was found in Alloy C-276, whereas a considerable amount is normally found in Alloy C. The maximum precipitation occurs at 1600 F (871 C) with a sharp drop at higher and lower temperatures. However, the times required to form these precipitates are at least 30 times longer than those of Alloy C.
- **Shin-Kun Ryi , Nong Xu a , Anwu Li, C. Jim Lim a, b , John R. Grace (12)** studied demonstrates palladium membranes can be electrolessly plated on aluminum oxide-modified porous Hastelloy with hydrazine using an EDTA-free bath. The plating bath temperature affected the membrane surface morphology, with the palladium grain size increasing with increasing temperature. A 7.5 μm thick membrane plating was obtained at room temperature. Helium leak testing confirmed that the membrane was free of defects. Hydrogen permeation test showed that the membrane had a hydrogen permeation flux of $3.3 \times 10^{-1} \text{ mol m}^{-2} \text{ s}^{-1}$ at a temperature of 823 K and at a pressure difference of 100 kPa. There was no measurable interdiffusion between the membrane film and the porous Hastalloy substrate at 823 K. This room temperature membrane plating method provides several advantages such as very high selectivity, stability, favorable energy efficiency and simplicity.
- **M. A. Rowley and E. A. Thornton(13)** described the viscoplastic behavior of advanced, high temperature, metallic alloys is characterized using the Bodner Partom unified constitutive model. Material parameters for both Hastelloy-X and Aluminum alloy 8009 are obtained for this model. The Bodner Partom constitutive model is summarized, and a detailed approach for determining the model parameters from experimental data is reviewed. Experimental methods for obtaining the mechanical test data are described. Bodner-Partom model parameters are determined from data obtained in uniaxial, isothermal, monotonic tension or compression tests and isothermal creep tests. Model predictions from the parameters determined are generated and compared to experimental data.
- **J. J. Burton , B. J. Berkowitz , R. D. Kane (14)** examined the surface composition of a cold-worked nickel-base superalloy, HASTELLOY C-276, by Auger electron spectroscopy. The alloy was subjected to annealing cycles at temperatures between 100 and 900°C. A number of elements, including C, N, O, P, S, and Si, segregated to the sample surface. The segregation behavior appears to be quite complex. Yet it can be understood in terms of five fundamental effects: kinetic limitations, thermodynamic temperature effects, cold-work annealing, depletion of trace impurities, and solute interactions.

- **Witha Berlian Kesuma Putri , Byeongwon Kang, Pham Van Duong , Won Nam Kang (15)** described MgB₂ is a promising candidate for superconductivity applications because of its metallic nature and its simple structure compared to other oxide superconductors. We have deposited MgB₂ thin films on the SiC buffered-Hastelloy substrates by a hybrid physical–chemical vapor deposition (HPCVD) method. SiC buffer layers of varying thicknesses were grown on the Hastelloy substrates by a pulsed laser deposition (PLD) technique. As the SiC buffer layers thicken, the grain size of MgB₂ films is distinctly decreased and the grains become much denser. MgB₂ film deposited on bare Hastelloy shows a sign of partial delamination at the interface. Interestingly, the delamination was considerably reduced when the SiC buffer layers with the thickness of 170 and 250 nm were added into the MgB₂ tape. This suggests that SiC buffer layers acted as an effective sticking agent, providing stronger adhesion to the MgB₂–Hastelloy interface, hence the reduced delamination.
- **Qian Q, Yan Liu, Hui Zhang, Yinsheng Li, Hanqin Liang, Zhengren Huang (16)** explained SiC p/Hastelloy composites were fabricated by pressureless Ti-activated infiltration process. The wetting and infiltration behaviors of Hastelloy on the SiC substrates and the interfacial reaction between the SiC particles and Hastelloy were investigated by real-time observation system, X-ray diffraction (XRD) and scanning electron microscopy (SEM) equipped with energy X-ray dispersive spectroscopy (EDS) system. The results demonstrated that the Hastelloy had a good wettability on SiC ceramic and could spontaneously infiltrate into the Ti-activated SiC preform. Moreover, intensive interfacial reaction similar to SiC/Ni system was found between the SiC particles and Hastelloy, which induced defects in the microstructure. In order to inhibit the interfacial reaction, Al₂O₃ coating on SiC particles was adopted as a diffusion barrier, which effectively reduced the extent of the interfacial reactions.
- **Jun CHEN, Jian-zhang WANG , Feng-yuan YAN , Qing ZHANG, Quan-an L (17)** investigated the corrosion and tribocorrosion behaviors of Hastelloy C276 alloy sliding against Al₂O₃ pin in artificial seawater, using a pin-on-disk tribometer integrated with a potentiostat for electrochemical control. The results show that the great decrease of open circuit potential and three orders of magnitude increase of corrosion current density occur caused by friction. There are clearly synergistic effect between corrosion and wear, resulting in corrosion-induced-wear and wear-induced-corrosion in tribocorrosion process. The contribution of pure mechanical wear to total material loss exceeds 70% in all sliding conditions, so mechanical wear is the dominant factor during tribocorrosion. For considering synergistic effect between corrosion and wear, the contribution of wear-induced-corrosion to total material loss is not very high although corrosion rate is greatly accelerated by friction. The fraction of corrosion-induced-wear to the total material loss is high and in the range of 14.6%–20.5% under all sliding conditions.
- **Xiang-Xi Ye , Hua Ai, Zhi Guo , Hefei Huang, Li Jiang, Jianqiang Wang, Xingtai Zhou, Zhijun Li (18)** described the effect of Fe ion impurity on the corrosion behavior of Hastelloy N (UNS N10003) alloy in molten FLiNaK salts at 850 °C has been investigated by combined synchrotron radiation and other characterization techniques. Results showed that Mo and Cr were depleted from the alloy surface, where Fe-rich layer formed. The corrosion process was mainly controlled by the redox reaction between Fe ion and Cr, and no new compound with high valence state formed in the alloy surface. The loss of Mo and Cr in

M₁₂C carbide occurred due to the presence of a concentration-gradient between M₁₂C carbide and matrix.

- **Liang YUAN , Rui HU, Tie-bang ZHANG , Jin-shan LI, Xiao-qing ZHANG (19)** investigated the oxidation behavior of Hastelloy C-2000 alloy in air at 800 °C and 1000 °C for 100 h, respectively. Oxidation kinetics and oxide scales morphologies were examined by mass gain measurement, scanning electron microscopy (SEM), X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS). The oxidation behavior of the alloy approximately follows a parabolic rate law. Moreover, annealing twins defect structure in matrix deteriorates the oxidation resistance of alloy due to the improvement of diffusion rates for alloying elements and oxygen atoms. At 800 °C, the microstructure is primarily composed of NiO and Cr_{1.3}Fe_{0.7}O₆ and the initial annealing twins structure is visible and Mo-rich phases are emerged to approach boundary of oxide scales. At 1000 °C, however, the morphology microstructure of oxide scales consists of oxide particle with fine Cr oxides and large Ni oxides by inlaying each other, whilst Mo-rich phases hardly appear closing to the interface of oxide scales.
- **Yuquan Guo, Dongjiang Wu, Guangyi Ma, Dongming Guo (20)** described a three-dimensional finite element model (FEM) was established to reveal the thermal-mechanical behaviors of pulsed laser welding (PLW) with and without trailing heat sink. Experiments were carried out to measure the welding temperature histories, residual distortions and solidification profiles. The simulation results agree well with the corresponding experimental measurements. The peak values of the temperature and transient longitudinal tensile stresses valleys in the weld increase as the cooling intensity increases from 5000 to 15,000 W/(m² K), while those of the temperature and transient longitudinal compressive stresses near the weld decrease. The peak values of the longitudinal residual compressive stresses and plastic strains, and the maximum deflections in longitudinal and transverse direction decrease as the cooling intensity increases from 5000 to 15,000 W/(m² K). The magnitudes of the transverse shrinkage distortions increase as the cooling intensity increases from 5000 to 15,000 W/(m² K). The proper cooling intensity to reduce the residual stresses and distortions of the PLW with the trailing heat sink is detected at 10,000 W/(m² K). The trailing heat sink is technically feasible for actual pulsed laser restraint welding in Hastelloy C-276 thin sheet structures.
- **Xinmei Yang, Yu , Xingtai Zhou , Huihao Xia (21)** explained Interaction between SiC and Hastelloy N alloy in LiF–NaF–KF salt for the application of SiC to molten salt reactors. Results reveal that Hastelloy N alloy and its corrosion products can induce the corrosion of SiC in salt. Ni can react with Si in salt to form silicide (Ni₃Si, NiSi). Cr²⁺ can react with SiC to form carbide (Cr₃C, CrC). Ni²⁺ can cause SiC with a thickness of 50 μm almost disappear after 45 days; thus, the Si content in salt can increase to 0.5 wt%. Raman spectrum indicates that Si in salt is in the form of [SiF].
- **G. Ma, F. Niu, D. Wu, Y. Qu (22)** observed on the welding quality requirement of Hastelloy C276 in the extreme environment, the electrochemistry corrosion property of laser welding Hastelloy C276 was evaluated in the neutral, acid and alkaline solutions, and the corroded surface was observed by the co-focal laser scanning microscope to confirm the corrosion mechanism. The results indicated, the corrosion trend of the weld was weaker than that of base metal in the neutral and acid solutions, but in the alkaline solutions, the corrosion trend of the base metal was weaker. However, the corrosion rate of the weld was much slower

than that of base metal in all solutions. At the point of corrosion mechanism, in the acid and alkaline solutions, the base metal and weld showed the uniform corrosion. However, in the neutral solution, the selective corrosion and intergranular corrosion occurred in the base metal and the weld, respectively.

- **D. Tomus, T. Jarvis, X. Wu, J. Mei, P. Rometsch, E. Herny, J.-F. Rideau, S. Vaillant (23)** described Selective Laser Melting (SLM) is steadily gaining acceptance across the manufacturing industry. Techniques for manufacturing components with complex geometries layer by layer have proven to be very effective in accelerating product development and hence reducing time to market. To build components by SLM from a nickel based super-alloy requires an understanding of process parameters and how they influence the microstructure, the degree of porosity and the properties. In this work, it was found that the as-fabricated density of parts manufactured from Hastelloy-X by SLM could be increased from 77 to 99% by decreasing the laser scan speed, and that the degree of cracking can be reduced by decreasing the amount of minor alloying additions such as Mn and Si.
- **Yun Luo, Wenchun Jiang, Weiya Zhang, Y.C. Zhang, W. Woo, S.T. Tu (24)** explained the brazed structures have geometrical discontinuities like fillets working as notches. These notches have great effect on creep crack initiation and propagation. This paper studies the notch effect on creep damage for Hastelloy C276-BNi2 brazed joint, and the effects of notch type, notch radius and notch angle on creep damage have been investigated. The results show that the creep damage initiates in the filler metal. Different notch types bring different stress states, and generate different stress triaxialities and equivalent creep strains (CEEQs), leading to different creep damages. The maximum creep damage is generated in the notch tip for V-type notch, while the maximum creep damage is located at 0.4 mm away from the notch tip for C-type notch. For U-type notch, the location of the maximum creep damage moves from the notch tip to the inside gradually as the notch radius increases. With the increase of notch radius and notch angle, the failure time of creep damage increases for U-type and V-type notches, while it decreases for C-type notch. The creep failure is prone to happen to V-type notch because it belongs to sharp notch.
- **Yixi Yang, Dong Zhou, Chengtao Yang, Fan Feng, Junsong Yang, Qijun Hu (25)** described Piezoelectric film based on flexible substrate, which is conductive and heat-proof, is very promising for cantilever beams to constitute vibration energy collectors. Sc-doped AlN thin films based on Hastelloy alloys flexible substrate were prepared by DC reactive magnetron sputtering under sputtering power from 110 W to 200 W. The crystal quality of ScAlN films was investigated. Results show that the sputtering power greatly influences the preparation of *c*-axis-oriented ScAlN thin films. The crystal quality first increases and then decreases with increase of sputtering power, reaching the best crystalline state at 170 W, presenting full width at half maximum of 2.3°.
- **Md.karim Baig, Dr.N.venkaiah (26)** observed Wire EDM (WEDM) is a versatile non-traditional machining process used to cut materials of high hardness and to produce very complex and intricate shapes on the wide variety of materials. Hardness of the material is not a constraint for WEDM. This advantage makes the WEDM to cut very hardened materials with ease. Parameters that affect the Material Removal Rate(MRR) and surface roughness mainly consists of pulse on time, pulse off time, discharge current, servo voltage, tension of wire, flushing pressure etc. so, it is very essential to set the parameters that control the outputs in an optimized condition so as get the maximum output. Work has been carried out to find the

optimal parameter settings for maximum MRR and minimum kerf (width of cut) for a nickel based alloy, HastelloyC276, a very high temperature, corrosion resistant alloy, using both Taguchi methods and Grey Relational Analysis (GRA).

- **H. M. Tawancy (27)** described HASTELLOY* alloy s is a commercial, solid solu* HASTELLOY is a registered trademark of Cabot Corporation tion-strengthened, nickel-base superalloy developed for applications where oxidation resistance, low thermal expansion and retained ductility after long-time exposure at elevated temperatures are prerequisites. Its typical heat treatment consists of annealing at 1340 K (1950 °F) followed by air cooling to produce an essentially single phase material. When specimens from annealed heats were aged at 810 K (1000 °F) for 1000 to 8000 h and then tensile tested at room temperature, it was found that relative to the annealed condition, the 0.2 pct yield strength had nearly doubled while about 70 pct of the tensile elongation was retained. It is the objective of this note to report on the formation of a long-range ordered phase that caused the observed strengthening.

III. FUTURE SCOPE

- Need for finding optimal combination of parameters for different tool materials used for work materials.
- Responses like roundness, circularity, cylindricity, machining cost etc may be considered in further research.
- For the estimation of process parameters, the work being carried out can be compared by considering different methods such as multiple relation analyses, ANOVA or F-Test. Similarly comparison can be made between Taguchi analysis Fuzzy control or Orthogonal techniques.
- A lot of research work still needs to be carried out in the field of Wire EDM by machining Super alloys such as Hastelloy composites, Different grades of Hastelloy utilizing other process parameters and using deferent Techniques.

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