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Study on mechanical properties of Inconel 625 and Incoloy 800H with nitrate based molten salts

ABSTRACT

Energy storage is the most indispensable technology in the recent days with augmented power demand, which helps in balancing the energy demand and production time. Among the broad spread of energy storage types, molten salts technology in concentrated solar plants is most economical, highly efficient with excellent duration on the storage timings. In this current effort, Inconel 625 and Incoloy 800H nickel based super alloys have been taken and heated with sodium nitrate and potassium nitrate molten salts. The super alloy substrates were coated with Yttria stabilized zirconia as thermal barrier coating which could enhances the heat resistance and corrosion resistance property of the base substrates. Both layered and non-coated super alloy samples were intense to a fairly accurate temperature of 1000^oC for different duration as 9, 12 and 15 hours. The mechanical properties of both unheated and heated specimens were compared with the results obtained from tensile test, compression test, hardness test, and impact test. The changes in the micro-structural properties were investigated with the support of SEM images and by XRD analysis. The mechanical properties of YSZ coated specimens are found to be better than the uncoated specimens; which increases the sustainability of the super alloys with the molten salts.

Keywords: *Inconel 625, Incoloy 800H, Yttria stabilized zirconia, Sodium nitrate, Potassium nitrate salts and hot corrosion.*

1. INTRODUCTION

Power production methods in modern days find its significant development in all aspects right from the material procurement to the final stage of power transmission and utilization. Among that, energy storage technology and its types play a vital role. Salts with high melting point and boiling point such as chloride-based salts, Nitrate based salts and Sulphate based salts can be termed as molten salts are extensively used in molten salts technology in energy storage devices. Nitrate based molten salts are expansively used for sensible thermal storage in Concentrated Solar Power (CSP) plants and thermal energy storage (TES) systems. They are the most capable materials for latent heat storage applications [1-3].

The limitation with this molten salt technology is high and aggravated corrosion behavior on the storing material, since storing is done in high temperature approximately 1000^oC. The storing material should withstand this aggressive environment, where continuous development has to be taken place for maintaining the sustainability of the storing material. Super alloys have exceptional heat resistant properties and preserve their hardness, strength, robustness and dimensional firmness at temperatures much superior than the normal operating temperature [4,5].

Super alloys have high tendency to resist oxidation corrosion, creep formation in high temperature environment. These metals were categorized according to their major matrix element; nickel, cobalt, or iron, and they hold numerous alloying elements including the refractory metals (Niobium, Molybdenum, Tungsten, and Tantalum), chromium, and titanium. Haynes 625 known as Inconel 625, Inconel 718, Incoloy 800H and Hastelloy are some of the Nickel based super alloys frequently used at temperatures above 600°C; they are broadly used

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in aerospace industry parts, marine/gas turbines, nuclear reactors, petrochemical plants, and medical/dental components. Even with high exposure timing, this super alloy exhibits high stability, resistance to the phase change, scaling formation both in micro and macro levels. [6-8]

The desired properties can also be enhanced by coating the super alloy specimens with rare earth elements like neodymium, yttrium, cerium, scandium...e tc. Yttria stabilized zirconia (YSZ) is one of the ceramic and thermal barrier coating which could influence in high degree of oxidation and corrosion resistance in the base substrate. Thermal spray coating method is frequently used for this YSZ coating on the nickel based super alloy substrates [9,10].

In this current research, both uncoated and YSZ coated Inconel 625 and Incoloy 800H super alloy specimens have been heated with a eutectic mixture of sodium nitrate and potassium nitrate molten salts to check the possibility for using the nickel based super alloy material as storage material for molten salts in CSP plants. This alloy material was experimented in the presence of sodium and potassium nitrate molten salts in aggressive temperature to an approximate value of 1000^{o}C. The mechanical behavior of these alloy' specimens were tested and compared with testing of Tensile test, Compression test, Impact test, Hardness test. The micro structural analysis of the super alloy specimens was performed with SEM (Scanning electron microscope) analysis and XRD (X-ray diffraction) analysis.

2. MATERIALS AND METHODS

Nickel alloys with high chromium content are termed as Inconel and Incoloy and molybdenum content are known as Hastelloy. Among the wide varieties, Inconel 625 and Incoloy 800H have been taken for this study because of its tendency to resist oxidation, carburization and other elevated temperature corrosion. As shown in figure 1, the specimens for mechanical testing and micro structural analysis have been prepared with laser beam machining process. The material composition for the Inconel and Incoloy 800H specimens was tested and confirmed their grade with OES FOUNDRY PRO ANALYSER setup.

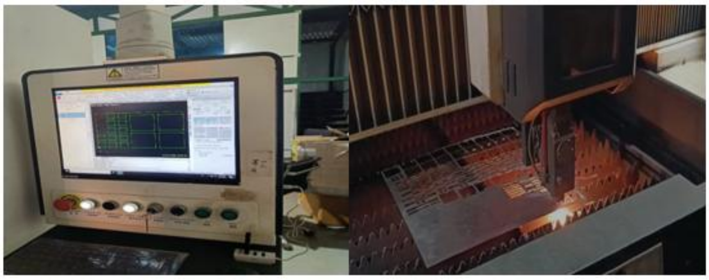

Figure -1 – Specimen preparation using laser beam machining setup

Slika 1. Priprema uzorka korišćenjem podešenog laserskog zraka za mašinsku obradu

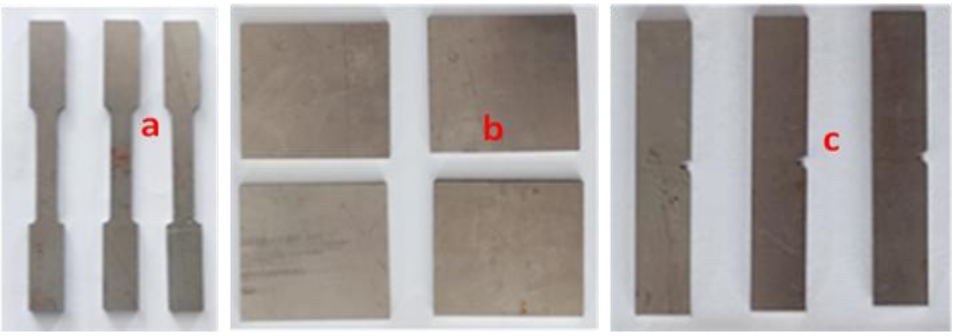

Figure -2 – a – Tensile test specimens, b- Compression test specimens, c – Impact test specimens used for mechanical testing

Slika 2. a – Uzorci za ispitivanje na zatezanje, b- Uzorci za ispitivanje kompresije, c – Uzorci za ispitivanje na udar koji se koriste za mehanička ispitivanja

The alloy specimens as shown in figure 2 were coated with YSZ ceramic material using thermal spray coating method to enhance the corrosion and scaling resistance properties of the specimens. NiCoCrAlY bond coat is used between the YSZ coating and the base substrate material. The YSZ coating has the thickness 150 microns whereas the bond coat thickness of 30 microns.

Both Sodium nitrate and potassium nitrate was preferred as molten salts with high melting point and boiling point. A eutectic mixture of 100 grams of molten salts as weight fraction 50 grams of both salts were taken and heated with the specimens in a muffle furnace to a temperature of 1000°C as shown in figure 3. The specimens were cleaned with methyl alcohol for removal of dust particles and any other scaling before the heating process. The specimens were heated to this high value for three different hours 9, 12 and 15 hours.

Figure -3 – Specimens in crucibles before and after the heating process

Slika 3. Uzorci u loncima pre i posle procesa zagrevanja

3. RESULTS AND DISCUSSION

The mechanical property trails such as tensile test, compression test, hardness and impact testing was done for analyzing the changes in the mechanical properties. Tensile test was carried out in a universal testing machine, thereby yield strength, ultimate tensile strength and % of elongation in 25mm GL were found for the different hour heated specimens. Hardness values of the specimens have been found using a Vickers hardness tester.

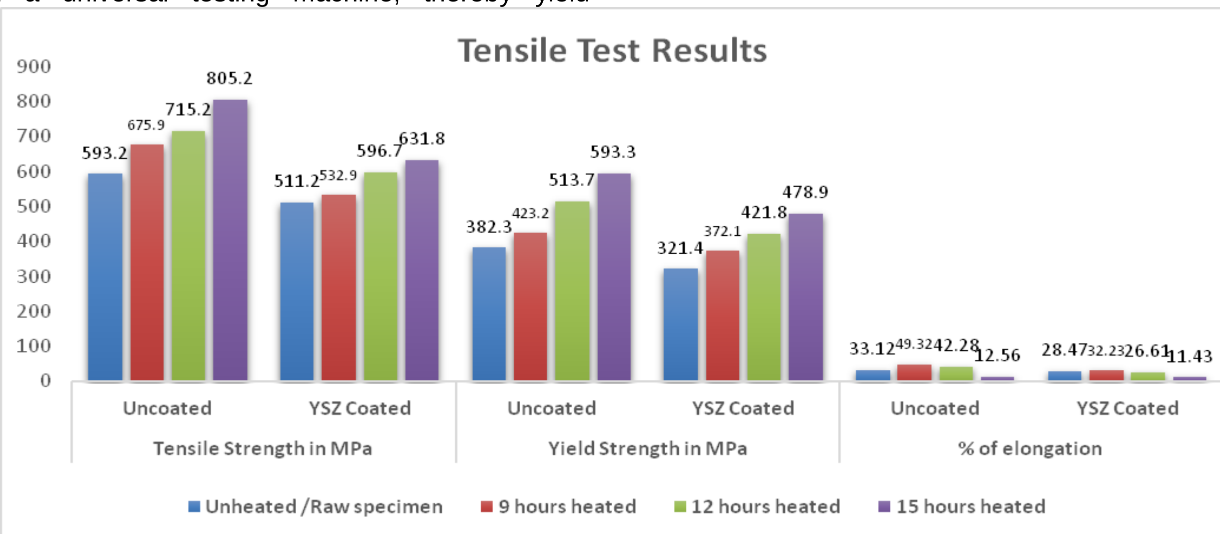

Figure 4. Tensile test results for both uncoated and YSZ coated specimens

Slika 4. Rezultati ispitivanja zatezanja i za nepremazane i za uzorke premazane YSZ

From the figure 4, the tensile strength of the uncoated specimens found to be increased to 13.94%, 20.56% and 35.73% for 9 hours, 12 hours and 15 hours heated specimens. Similarly, for YSZ coated specimens the tensile strength was increased to 4.07%, 14.32% and 19.08% respectively for the heated specimens. The yield strength of the uncoated specimens increased to 9.66%, 25.57% and 35.56% for 9 hours, 12 hours and 15 hours heated specimens. For YSZ coated specimens, the yield strength was increased to 13.62%, 23.80% and 32.88% respectively for the heated specimens. Thus, YSZ thermal barrier coating results in decrease in tensile strength and yield strength by increasing the stiffness of the substrate material.

The compression test was carried out in box compression tester equipment to determine the compression load carrying capacity of the heated specimens.

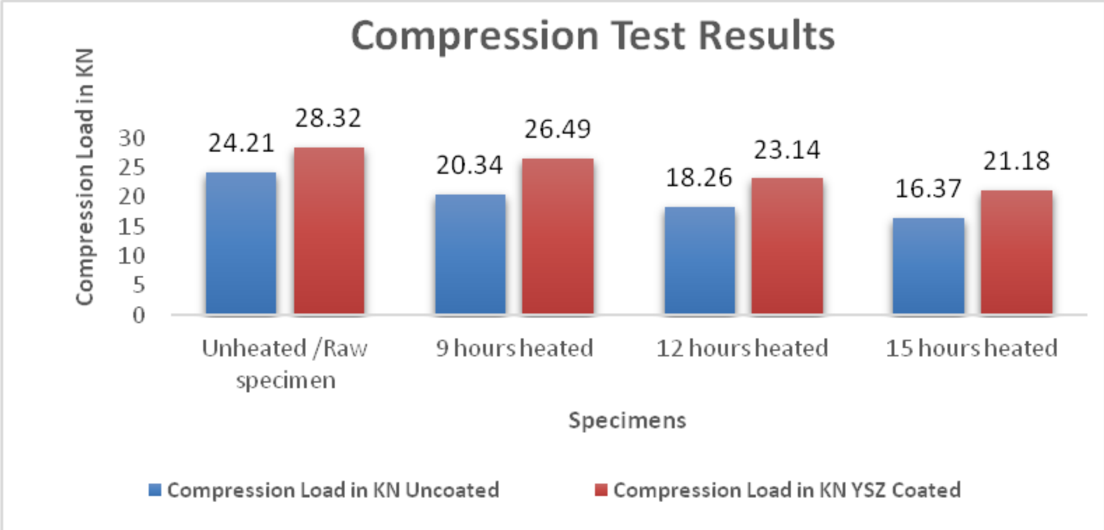

Figure 5. Compression test results

Slika 5. Rezultati testa kompresije

The compression loads of the heated specimens are decreased to 15.98%, 24.57% and 32.38% from the unheated raw specimen as shown in figure 5. The YSZ coated specimens are resulted in 6.46%, 18.29% and 25.21% respectively from the unheated and YSZ coated specimens.

The hardness / rigidity value of the experimented specimens was assessed using a Rockwell B hardness tester and the average values of the hardness for the heated specimens are tabulated as follows.

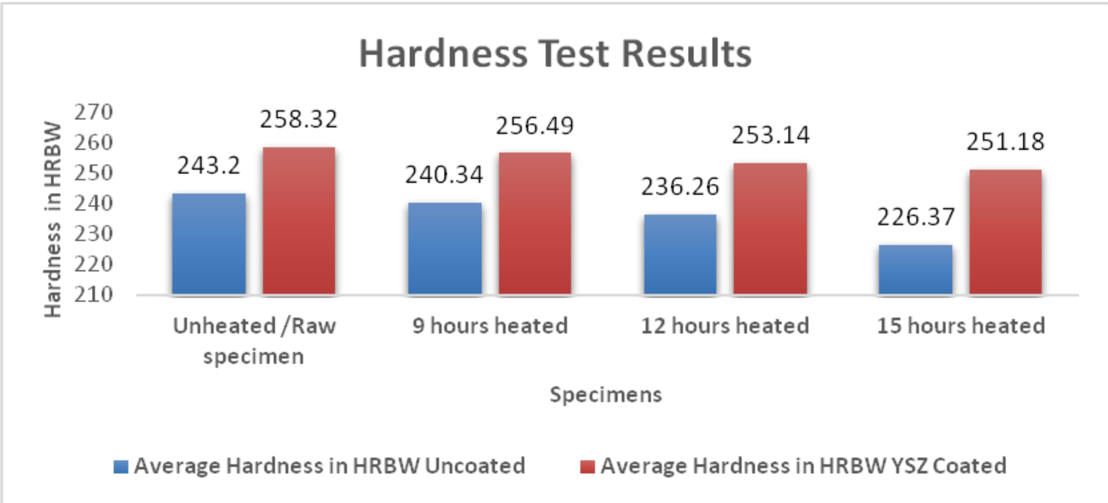

Figure 6. Hardness test results

Slika 6. Rezultati ispitivanja tvrdoće

From figure 6, the hardness value of the 15 hours heated specimens in both uncoated and coated specimens are decreased to a maximum value of 6.78% and 2.76% respectively. Thus, the YSZ coating influences the substrate material to enhance its mechanical properties and has minimal influence in heating when compared with the uncoated specimens.

The impact test was carried out in a Charpy impact 150 Joule machine to evaluate the specimen's capacity to withstand high-rate loading. The impact test resulted in heated specimens with shear lips whereas the unheated specimens are not having any jagged edges. So, the specimens are having increase in their ductility because of the aggressive heating of the specimens.

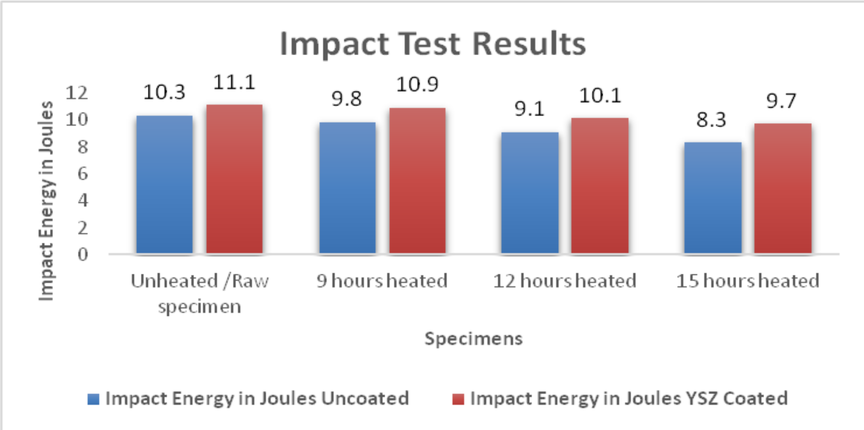

Figure 7. Impact test tesults
Slika 7. Rezultati ispitivanja uticaja

The impact energy of the heated specimens was decreased to a maximum value of 19.41% for the uncoated specimens and 12.61% for the YSZ coated specimens as shown in figure 7. The high rate of resistance to the temperature is well evident in the YSZ coated specimens. The coating increases the high degree of resistivity towards the thermal and fatigue load can be incidental from the impact test results.

3.1. Micro structural analysis

For analysis the changes in the micro structure scanning electron microscope images were taken. From the figure 8 (SEM images of the heated specimens), the pores in the alloys specimens are found to be in a lesser amount on YSZ coated specimens. YSZ coated specimens are highly resist the corrosion and void formation, any degradability of the substrate material.

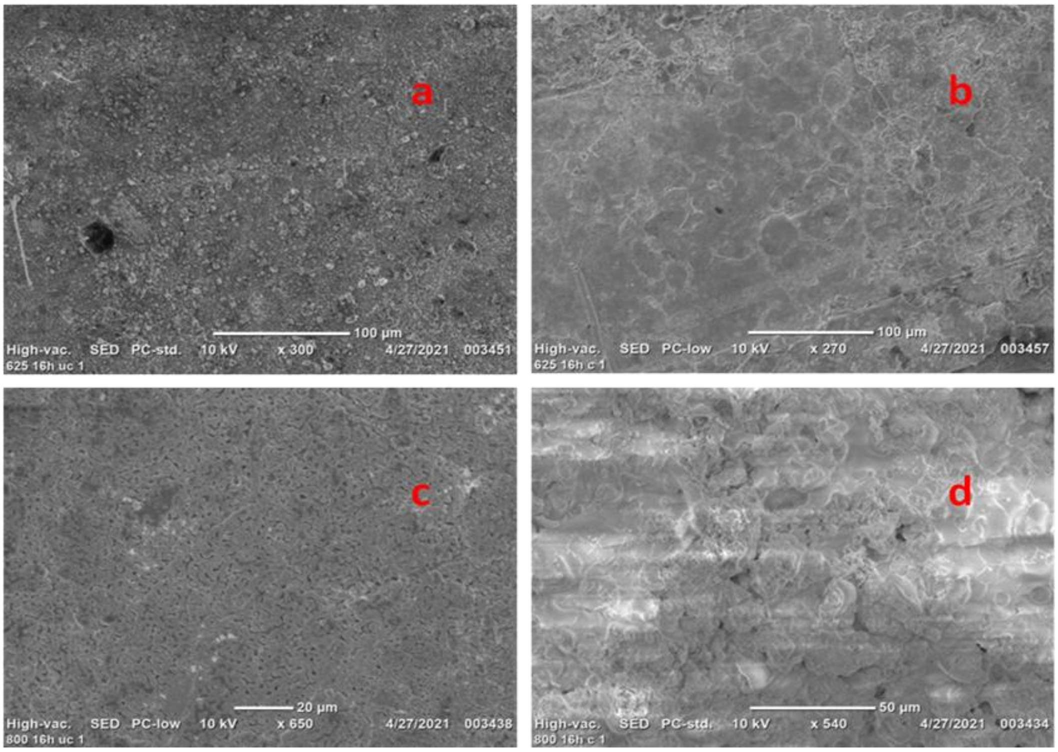

Figure 8. a –SEM image of 15 hours intense Inconel 625 uncoated sample, b - SEM image of 15 hours intense Inconel 625 –YSZ coated sample, c - SEM image of 15 hours intense Incoloy 800H uncoated sample, d - SEM image of 15 hours intense Incoloy 800H - YSZ coated sample

Slika 8. a –SEM slika 15 sati intenzivnog Inconel 625 nepremazanog uzorka, b - SEM slika 15 sati intenzivnog uzorka Inconel 625 – premazanog YSZ, c - SEM slika 15 sati intenzivnog nepremazanog uzorka Incoloi 800H, d - SEM slika 15 sati intenzivnog uzorka Incoloi 800H - premazanog YSZ

X-ray diffraction analysis was performed to comprehend about the crystallographic structure of the material. It also discloses the information related to the atomic and molecular structure of the crystal material.

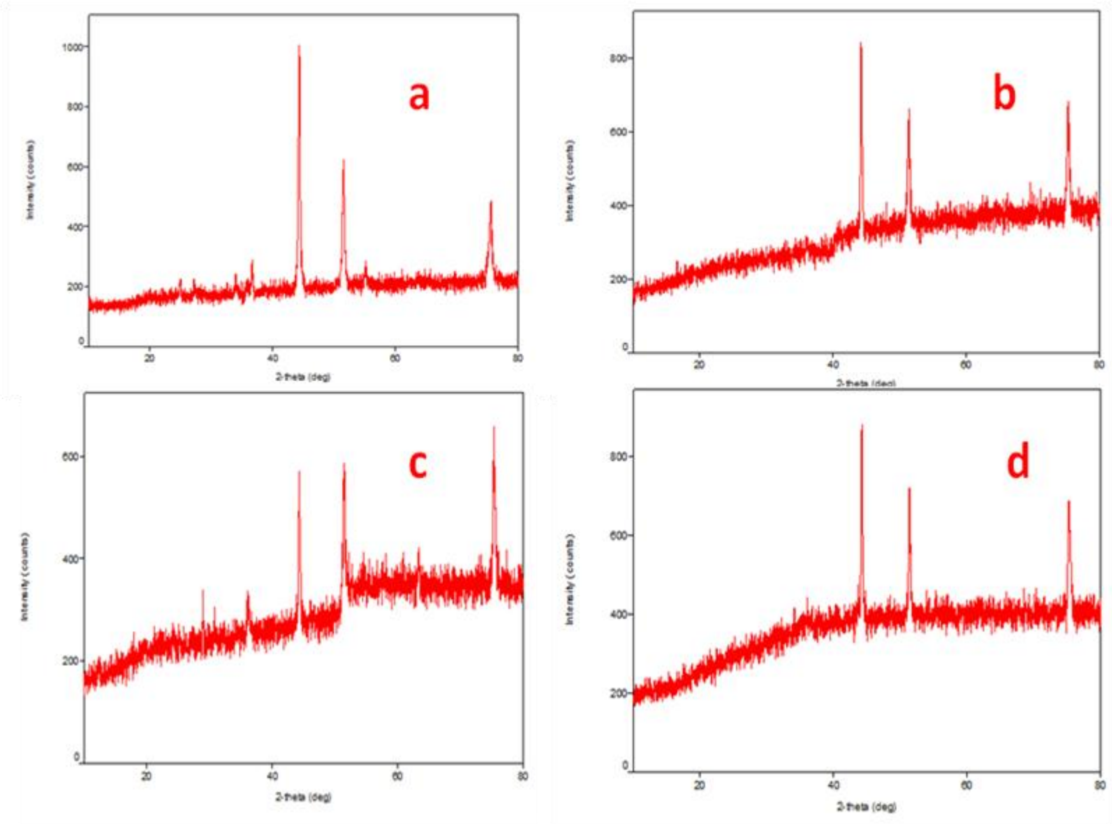

Figure 9 a –XRD result of 15 hours intense Inconel 625 uncoated sample, b - XRD result of 15 hours intense Inconel 625 –YSZ coated sample, c - XRD result of 15 hours intense Incoloy 800H uncoated sample, d - XRD result of 15 hours intense Incoloy 800H - YSZ coated sample

Slika 9. a – XRD rezultat 15 sati intenzivnog uzorka Inconel 625 bez premaza, b - XRD rezultat 15 sati intenzivnog uzorka Inconel 625 – premazanog YSZ, c - XRD rezultat 15 sati intenzivnog uzorka Incoloi 800H bez premaza, d - XRD rezultat 15 sati intenzivnog uzorka Incoloi 800H - premazanog ISZ

From the figure 9 (XRD analysis), the YSZ coated Inconel 625 and Incoloy 800H specimens are not having scaling deposits of nitrate-based elements on the base substrate, whereas in uncoated specimens the sodium and potassium elemental deposits were found to be in minimum scale.

4. CONCLUSION

In this current investigation, a solution to the current constraint in the molten salt's technology has been attempted by trailing Inconel 625 and Incoloy 800H with nitrate based molten salts. Since the physical properties of sodium and potassium nitrate are quite similar, a eutectic mixture both salts were taken. Yttria stabilized zirconia thermal barrier coating is used to increase the diverse resistance properties of the alloy specimens. After heating the alloy specimens for different hours, the following conclusions were recommended.

- Eutectic mixture of sodium and potassium nitrate can be used in CSP plants for thermal energy storage applications.
- Inconel 625 and Incoloy 800H super alloy material can be used for storing the molten salts in high aggressive temperature such as 1000^{o}C since it has nominal effect on both oxidation corrosion and carburization.
- The super alloy material can be coated with YSZ element which results in better-quality mechanical properties thereby increasing the sustainability of the storage material for a longer phase. The implication can be highly supported by the results of tensile, compression, hardness and impact tests.
- From the micro structural analysis, the least influence of corrosion can be seen on the coated specimens.

This investigation can further be extended with attempting varieties of molten salts, super alloy specimens and thermal barrier coatings with rare earth elements in future.

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IZVOD

STUDIJA MEHANIČKIH SVOJSTVA INCONEL 625 I INCOLOI 800H SA ISTOPLJENIM SOLIMA NA BAZI NITRATA

Skladištenje energije je najznačajnija tehnologija poslednjih dana sa povećanom potražnjom za energijom, koja pomaže u balansiranju potražnje za energijom i vremena proizvodnje. Među široko rasprostranjenim vrstama skladištenja energije, tehnologija rastopljenih soli u koncentrisanim solarnim postrojenjima je najekonomičnija, veoma efikasna sa odličnim trajanjem u vremenskom periodu skladištenja. U ovom trenutnom pokušaju, Inconel 625 i Incoloi 800H superlegure na bazi nikla su uzete i zagrejane sa rastopljenim solima natrijum nitrata i kalijum nitrata. Podloge od super legure su obložene cirkonijumom stabilizovanim itrijem kao premazom za termičku barijeru koji može poboljšati otpornost na toplotu i otpornost na koroziju osnovnih supstrata. I slojeviti i neobloženi uzorci super legure bili su intenzivni do prilično tačne temperature od 1000^{0}C u različitom trajanju od 9, 12 i 15 sati. Mehanička svojstva i nezagrejanih i zagrejanih uzoraka upoređena su sa rezultatima dobijenim testom na zatezanje, ispitivanjem kompresije, testom tvrdoće i ispitivanjem udarca. Promene u mikrostrukturnim osobinama su ispitivane uz podršku SEM slika i KSRD analizom. Utvrđeno je da su mehanička svojstva uzoraka obloženih ISZ bolja od neobloženih; što povećava održivost super legura sa rastopljenim solima.

Ključne reči: *Inconel 625, Incoloi 800H, itrij stabilizovan cirkonijum, natrijum nitrat, soli kalijum nitrata, vruća korozija.*

Naučni rad

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