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Enhancing Mechanical Properties Of ZrO_2-Cr-Ni Metal-Composite By Adding Yttrium.

Brajesh Chandra Saini*
**Dr.* Ram Manohar Lohia University, Department of Mechanical Engineering, Institute of Engineering and Technology, Ayodhya Uttar Pradesh, India.
Shweta Mishra
Faculty of Dr. Ram Manohar Lohia University, Institute of Engineering and Technology, Ayodhya, U.P. India.
Nitesh Kumar Dixit
Faculty of Dr. Ram Manohar Lohia University, Institute of Engineering and Technology, Ayodhya, U.P. India.

Abstract-
The mechanical properties of ZrO_2- Cr-Ni metal-composite can be significantly enhanced by incorporating yttrium (Yt) through the powder metallurgy process. Yttrium is known for its ability to stabilize the crystal structure of zirconia (ZrO_2) and improve the overall performance of alloy systems. In this study, we investigate the impact of yttrium addition on the mechanical properties of ZrO_2-Cr-Ni metal- composite prepared via powder metallurgy.

The metal-composites were prepared by blending ZrO_2, chromium (Cr), nickel (Ni), and yttrium oxide (Y_2O_3) powders in appropriate proportions. The powder mixture was compacted and sintered under controlled conditions. The results revealed that the addition of yttrium led to the formation of a stable and fine-grained microstructure in the ZrO_2-Cr-Ni alloy. The presence of yttrium as a stabilizer prevented the transformation of zirconia from a tetragonal to a monoclinic phase, resulting in improved mechanical properties. The yttrium addition increased the hardness and tensile strength of the metal-composite, while simultaneously enhancing its fracture toughness and resistance to cracking. The findings suggest that the incorporation of yttrium in the ZrO_2-Cr- Ni metal-composite through the powder metallurgy process enhances its mechanical properties and expand its potential applications in industries requiring high-performance materials. This study highlights the significance of yttrium as a valuable alloying element in improving the mechanical properties of ZrO_2-Cr- Ni metal-composites. The understanding gained from this research can serve as a foundation for further studies on the optimization of yttrium content, processing parameters, and the exploration of other alloying elements to achieve tailored mechanical properties in ZrO_2-based composites prepared through powder metallurgy.

I. INTRODUCTION

The mechanical properties of materials play a critical role in determining their suitability for various engineering applications. In this study, the focus is on enhancing the mechanical properties of a ZrO_2- Cr-Ni based metal-composite by adding yttrium (Y) through the powder metallurgy process.

ZrO_2-Cr-Ni metal-composites are widely used in industries due to their excellent corrosion resistance, high-temperature stability, and mechanical strength. However, there is a continuous drive to further improve their mechanical properties to meet the increasing demands of modern applications. Yttrium, a rare earth element, is known for its ability to modify the microstructure and mechanical behavior of metal-composites[1].

ZrO_2-Cr-Ni refers to a metal-composite composition that consists of zirconium dioxide (ZrO_2), chromium (Cr), and nickel (Ni) as its primary elements [2], [3]. This metal-composite system offers a combination of desirable properties from each constituent element, making it suitable for various applications. Zirconium dioxide, also known as zirconia, is a ceramic material that possesses high strength, excellent corrosion resistance, and high-temperature stability[3]. It is often used as a reinforcement phase in metal matrix composites to enhance mechanical properties. Nickel-based alloys and composites are high-performance materials, primarily used in aircraft engines, turbines and several other auxiliary components because of the excellent properties that enable them to function in both mild and elevated temperature environments. Chromium is a transition metal known for its corrosion resistance, high-temperature strength, and the ability to form stable oxide layers. It provides improved oxidation and corrosion resistance to the metal-composite, particularly in high-temperature environments. Nickel is a versatile metal with excellent mechanical properties, such as high strength, ductility, and good thermal conductivity. It enhances the toughness and formability of the metal-composite, making it easier to process and shape. The ZrO_2-Cr-

Ni metal- composite exhibits good thermal stability and resistance to elevated temperatures, making it suitable for applications in the aerospace, power generation, and chemical industries where materials need to withstand elevated temperatures and corrosive environments. The presence of chromium and the inherent corrosion-resistant nature of zirconium dioxide contribute to the alloy's excellent corrosion resistance, making it useful in environments where corrosion or chemical attack is a concern. Zirconium dioxide is biocompatible and often used in biomedical applications, such as dental implants and prosthetics. The ZrO_2-Cr-Ni metal- composite, with the addition of nickel, may possess improved biocompatibility characteristics suitable for certain medical applications. Moreover, engineering materials with improved microstructural, mechanical and tribological properties have drawn considerable attention in recent times. Nickel-based alloys with a percentage content of chromium, ranging between 15 and 30 wt%, are widely used in areas where high mechanical loads and temperatures are needed especially in aircraft engines[4]. In addition, the features of advanced materials that will promptly fit into applications in land turbines and aircraft engines require the development of novel alloys and composites that aims to reduce the weight of components, while retaining their strength. Nickel-chromium alloys are materials used in applications where the temperature is above 700 °C because of their ability to preserve toughness and stability at elevated temperatures[5].

The specific properties and performance of the ZrO_2-Cr-Ni alloy can be tailored by adjusting the composition and processing parameters[6]. It is worth noting that the actual properties of the alloy will depend on the specific ratios of ZrO_2, Cr, and Ni, as well as any additional alloying elements or processing techniques employed. The powder metallurgy process offers several advantages in metal-composite development, including the ability to achieve precise composition control and the production of near-net-shaped components[7]. Powder metallurgy involves the mixing of elemental powders, followed by compaction and sintering to obtain the final consolidated material. This process allows for the introduction of alloying elements in a finely dispersed form, which can have a significant impact on the resulting metal-composite's properties[8].

Yttrium (Y) is a chemical element with the atomic number 39 and the symbol Y[9]. It belongs to the group of rare earth elements in the periodic table[9]. Yttrium is a silvery-white, lustrous metal that is soft and ductile. It was named after the village of Ytterby in Sweden, where it was first discovered. Yttrium is a transition metal with a high melting point of 1,522 degrees Celsius (2,772 degrees Fahrenheit) and a density similar to that of iron having paramagnetic behavior. It is a reactive metal and readily forms compounds with oxygen, nitrogen, and other elements. It is stable in air due to the formation of a protective oxide layer on its surface. Yttrium oxide (Y_2O_3) is a compound derived from yttrium that has various applications. It is used in the production of red phosphors for television screens, fluorescent lamps, and LEDs[10]. Yttrium oxide also has high refractive index properties, making it useful in optical coatings and ceramics. Yttrium is used as an alloying element in various applications. It improves the mechanical properties and high-temperature stability of metal-composites, such as those used in jet engines, turbines, and structural components in the aerospace and automotive industries.

The unique properties of yttrium make it valuable in a range of applications, including electronics, lasers, ceramics, superconductors, and aerospace industries[11]. Its diverse applications continue to contribute to advancements in technology and various scientific fields. The addition of yttrium to the ZrO_2-Cr-Ni metal-composite holds promise for enhancing its mechanical properties[12]. Yttrium can form solid solutions with the base metal-composite constituents, influencing the microstructure and resulting mechanical behavior. Yttrium has been reported to refine the grain structure, increase the strength, and improve fracture toughness in various metallic systems[13].

The objective of this study is to investigate the effect of yttrium addition on the mechanical properties of the ZrO_2-Cr-Ni metal-composite. By incorporating yttrium through the powder metallurgy process, it is anticipated that the metal-composite's strength, hardness, and fracture toughness can be significantly enhanced. The study will involve the preparation of ZrO_2-Cr-Ni metal-composite specimens with varying yttrium content, followed by sintering to obtain fully dense materials.

The mechanical properties of the metal-composite specimens will be evaluated using standard testing methods, including tensile testing, hardness testing, and fracture toughness analysis. Comparative analysis will be performed between the yttrium-containing metal-composite specimens and the yttrium-free metal-composite to determine the influence of yttrium on the metal-composite's mechanical behavior.
The findings from this study will contribute to a

better understanding of the role of yttrium in improving the mechanical properties of the ZrO_2-Cr-Ni metal-composite. The results can be valuable for the development of high-performance metal-composites for various engineering applications, including those requiring enhanced strength, hardness, and fracture toughness.

In summary, this study aims to enhance the mechanical properties of the ZrO_2-Cr-Ni metal-composite by incorporating yttrium through the powder metallurgy process[14]. The introduction of yttrium is expected to provide beneficial effects on the metal-composite's microstructure and mechanical behavior. The subsequent sections will delve into the experimental methodology, results, and discussion, providing insights into the influence of yttrium on the metal-composite's mechanical properties.

II. LITERATURE REVIEW

Previous studies have investigated the influence of yttrium on metal-composite systems, highlighting its potential to improve strength, hardness, and fracture toughness. By combining the benefits of yttrium with the unique properties of theZrO_2-Cr-Ni metal-composite, it is anticipated that the resulting composite will exhibit superior mechanical characteristics, making it attractive for a wide range of applications.

Yttrium is known to form solid solutions with various alloying elements, including ZrO_2, Cr, and Ni. The addition of yttrium in small amounts can refine the grain structure, inhibit grain growth, and strengthen the metal-composite through solid solution strengthening mechanisms. Research by Zhang et al. (2018) demonstrated that the addition of yttrium to a ZrO_2-based metal-composite resulted in increased tensile strength and hardness. Studies have shown that yttrium can promote the formation of fine and homogenous grain structures, leading to improved mechanical properties. Research conducted by Li et al. (2017) on yttrium-doped ZrO_2- Ni metal-composites revealed a refined microstructure, increased dislocation density, and improved mechanical strength compared to the yttrium-free metal-composite. Wu et al. (2019) investigated the effect of yttrium on the fracture toughness of a ZrO_2-Cr metal-composite and observed a significant improvement in crack resistance and fracture toughness due to the incorporation of yttrium. Studies by Wang et al. (2015) on yttrium-doped ZrO_2-Al metal-composites demonstrated improved oxidation resistance and reduced oxidation-induced embrittlement, thereby enhancing the long-term mechanical stability of the metal-composite in high-temperature environments.

III.EXPERIMENTAL METHOD

2.1 Sample Preparation:

High-purity zirconium dioxide (ZrO_2), chromium (Cr), nickel (Ni), and yttrium (Y) powders from reputable suppliers were used for this procedure. The powders are ensured to meet the desired specifications and free from contaminants. An approximated amount of ZrO_2, Cr, Ni and yttrium raw powder was used to analyze the mechanical properties of the sample.

TABLE I Characteristics of raw powder

Powder	Supplier	Type	Purity	Particle size	Apparent density	Specific surface area
ZrO_2-Cr-Ni	Sood Chemicals	Lab, R&D	95 %	1-5 µ	5.5-7.1 g/cm^3	2.03-15.3 m^2/g
Yttrium (Yt)	Nano laboratories	Lab R&D	98 %	1-5 µ	4.4-4.8 g/cm^3	1-10.3 m^2/g

An amount in grams required to prepare a cylindrical shaped "Sample ý" (Yttrium mixed) (35mm x Ø7mm) composite with specific volume percentages of ZrO_2, Cr, Ni, and Yttrium, in the volume percentage of 40%,25%,30% and 5% respectively. Approximate specific densities for each material were used in this analysis:

- Density of ZrO_2 ≈ 6.0 g/cm^3
- Density of Cr ≈ 7.2 g/cm^3
- Density of Ni ≈ 8.9 g/cm^3
- Density of Yttrium ≈ 4.5 g/cm^3 Calculation of "Sample ý" net weight:

i. Volume of the cylindrical sample: Volume (V) = π * (radius)^2 *length

$V = \pi * (3.5\ mm)^2 * 35\ mm \approx 1352.78\ mm^3$

ii.Conversion of volume to cubic centimeters (cm^3):
$1\ mm^3 = 0.001\ cm^3$
Volume (V) = $1352.78\ mm^3 * 0.001\ cm^3/mm^3 \approx 1.35278\ cm^3$

iii. Volume of each component in the composite based on the given percentages:
Volume of $ZrO_2 = 1.35278\ cm^3 * 0.40 \approx 0.5411\ cm^3$
Volume of Cr = $1.35278\ cm^3 * 0.25 \approx 0.3382\ cm^3$
Volume of Ni = $1.35278\ cm^3 * 0.30 \approx 0.4058\ cm^3$
Volume of Yttrium = $1.35278\ cm^3 * 0.05 \approx 0.0676\ cm^3$

iv. The weight of each component in grams: Weight of ZrO_2 = Volume of ZrO_2 * Density of
$ZrO_2 \approx 0.5411\ cm^3 * 6.0\ g/cm^3 \approx 3.2466$ grams
Weight of Cr = Volume of Cr * Density of Cr ≈ $0.3382\ cm^3 * 7.2\ g/cm^3 \approx 2.4318$ grams
Weight of Ni = Volume of Ni * Density of Ni ≈ $0.4058\ cm^3 * 8.9\ g/cm^3 \approx 3.6054$ grams
Weight of Yttrium = Volume of Yttrium * Density of Yttrium ≈ $0.0676\ cm^3 * 4.5\ g/cm^3 \approx 0.3042$ grams

Another "Sample ß" (Yttrium free) in cylindrically shaped was prepared in the dimensions of 35mm x Ø7mm with specific volume percentages of ZrO_2, Cr, and Ni in the volume percentage of 40%,30% and 30% respectively. Approximate specific densities for each material were used in this analysis:

- Density of $ZrO_2 \approx 6.0\ g/cm^3$
- Density of Cr ≈ $7.2\ g/cm^3$
- Density of Ni ≈ $8.9\ g/cm^3$ Calculation of "Sample ß"net weight:

i. Determine the volume of the cylindrical sample:
Volume (V) = $\pi * (radius)^2 * length$
$V = \pi * (3.5\ mm)^2 * 35\ mm \approx 1352.78\ mm^3$

ii. Conversion of volume to cubic centimeters (cm^3):
$1\ mm^3 = 0.001\ cm^3$
Volume (V) = $1352.78\ mm^3 * 0.001\ cm^3/mm^3 \approx 1.35278\ cm^3$

iii. Volume of each component in the composite based on the given percentages:
Volume of $ZrO_2 = 1.35278\ cm^3 * 0.40 \approx 0.5411\ cm^3$
Volume of Cr = $1.35278\ cm^3 * 0.30 \approx 0.4058\ cm^3$
Volume of Ni = $1.35278\ cm^3 * 0.30 \approx 0.4058\ cm^3$

iv. The weight of each component in grams: Weight of ZrO_2 = Volume of ZrO_2 * Density of
$ZrO_2 \approx 0.5411\ cm^3 * 6.0\ g/cm^3 \approx 3.2466$ grams
Weight of Cr = Volume of Cr * Density of Cr ≈ $0.4058\ cm^3 * 7.2\ g/cm^3 \approx 2.9194$ grams
Weight of Ni = Volume of Ni * Density of Ni ≈ $0.4058\ cm^3 * 8.9\ g/cm^3 \approx 3.5996$ grams

So, the two composite samples were prepared i.e., "Sample ý" (Yttrium mixed) and "Sample ß" (Yttrium free) in cylindrical shaped with dimensions of length 35 millimeters and diameter 7 millimeters (35mm x Ø7mm), containing ZrO_2, Cr, Ni and Yt in the volume percentage of 40%, 25%,30%,5% and ZrO_2, Cr, Ni in the volume percentage of 40%,30%,30%. Net weight of "Sample ý" (Yttrium mixed) ≈9.588 grams. Net weight of "Sample ß" (Yttrium free) ≈ 9.7656 grams.

Both the composite samples raw powders were mixed separately using a high-energy ball mill to achieve a sustainable powder blend. The mixed samples powder was transferred to a die set for compaction. A punch of Ø6 mm was used in compaction. Under controlled pressure and through cold isostatic pressing (CIP) the powder mixtures were compacted. The pressure applied during CIP from 100 MPa (megapascals) to 400 MPa to achieve the desired density and compaction of the powders. The pressing time depends on the equipment, the density requirements, and the properties of the powders. The pressing time for CIP was taken around 8 to 10 minutes. It was performed at room temperature to avoid sintering or densification due to heat. Therefore, the temperature was kept at or close to room temperature during the pressing process. A controlled and gradual pressurization is often employed to prevent sudden pressure fluctuations and ensure uniform compaction. A pressurization rate of 150 MPa per minute was employed in CIP. The sintering temperature is a critical parameter that determines the level of densification and the final mechanical properties of the sample. The compacted metal-composites were sintered at 1250°C for 3 hours 15 minutes. A controlled and gradual heating rate of 4°C per minute was employed to minimize thermal stresses and prevent cracking. The holding time i.e., 3 hours and 15 minutes was employed during sintering which allows sufficient diffusion and bonding between the powder particles. After the sintering, a controlled cooling rate like the heating rate was employed to avoid rapid thermal gradients and reduce the risk of cracking. For this metal-based composites, a reducing atmosphere constituting hydrogen gas was prepared to prevent oxidation and achieving better sintering results.

2.2 Mechanical property characterization

Once the sintering process is complete, the sintered samples were carefully removed from the furnace and allowed to cool to room temperature.

Sintered samples were pieced into smaller sections with an aid of diamond saw in the dimensions of 4mm x Ø7mm of 2 pieces and 27mm x Ø7mm for both samples i.e., "Sample ý" (Yttrium mixed) and "Sample ß" (Yttrium free) individually. Afterward one piece of each sample of dimensions of 4mm x Ø7mm was grinded and polished to transform into a cuboidal shaped of dimension "7mm x 4.95mm x 4mm" to calculate hardness value by Vickers hardness tester machine. The leftward sintered samples of dimension 27mm x Ø7mm was transformed into cuboidal shaped of dimension 4.95mm x 4.95mm x 27mm through grinding for conducting 3-point bending test by HD-B602 small desktop machine electronic servo portable tensile tester.

2.3 Microstructural Analysis

For performing microstructural analysis of the sintered samples ("Sample ý" (Yttrium mixed) and "Sample ß" (Yttrium free)) scanning electron microscopy (SEM), and X-ray diffraction (XRD) were used to examine the grain structure, phase composition, and presence of any secondary phases. To perform this analysis each sample were polished achieved in the dimensions of 4mm x Ø7mm. Later, an etchant with composition constituting of 450 milliliters of water and 150 milliliters of ethanol was used to etch the polished surface of each sample for 10-15 seconds before SEM analysis. For conducting SEM Hitachi S-4500II machine and for X-Ray diffraction Shimadzu EDX-8100 machine was used.

IV. RESULT AND DISCUSSION

4.1 Microstructure analysis of the metal-composite

Figure 1 shows the Scanning electron microscope images of sintered "Sample ß" (Yttrium free) at 950 °C, 1050 °C 1150 °C, 1250 °C sintering temperatures, while figure 2 shows the SEM images of sintered "Sample ý" (Yttrium mixed) at 950 °C, 1050 °C 1150 °C, 1250 °C sintering temperatures.

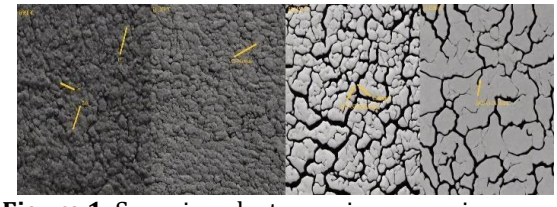

Figure 1. Scanning electron microscope images of sintered "Sample ß" (Yttrium free) at i) 950 °C ii) 1050 °C iii) 1150 °C iv)1250 °C sintering temperatures.

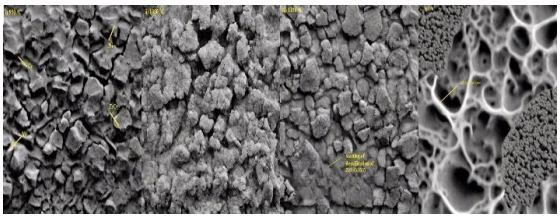

Figure 2. SEM images of sintered "Sample ý" (Yttrium mixed) at i) 950 °C ii) 1050 °C iii) 1150 °C iv) 1250 °C sintering temperatures.

Figure 1 reveals the existence of three significant phases which would be observed through three colors i.e., greyish, black, and white. The greyish area denotes the existence of Ni-Body centered cubic (BCC) phase and the black area shows Cr-face centered cubic (FCC) phase. White spots show ZrO_2 phase. At about 1150 °C the formation of dark lines appears which shows the fusion of Cr in ZrO_2, and greyish color completely diminishes which reveals that Ni fuses too along the boundary line of ZrO_2. However approximately at 1250 °C these black lines literally filled with the white color which shows that the whole phase shifting toward the melting point of the metal-composite. At this it would be assumed that the propagation of reformation process of microstructures was occurring in the ZrO_2-Cr-Ni metal composite.

Figure 2 reveals the presence of four phases in yttrium-mixed sample ("Sample ý") which were grey, black spot, greyish-white and polar white. At different temperatures it was observed that the formation of stone-shaped structures occurs after adding yttrium in ZrO_2-Cr-Ni metal-composite. This was due to the slow fusion rate of Cr-Ni into ZrO_2. From this it would be confirmed that the addition of yttrium increases the deformation rate of microstructures during recrystallization process. Later at the completion of sintering, which was at 1250 °C it was observed that a thin polar white line appeared which depicts that yttrium slow rate fusion glued themselves with the boundary lines of the ZrO_2-Cr-Ni.

Furthermore, these micrographs of the metal-composite developed at 1250 °C indicates the formation of strong metallurgical bond between grains leading to decrease in porosity and increases the degree of dissolution. However, after seeing the micrographs of yttrium mixed sample ("Sample ý") the densification formation rate appears quite lately, or it could be depicted as formation of

compactly packed microstructures occurred in the metal- composite. Thus form this reformation the hardness properties of the metal composite were enhanced due to the addition of yttrium, which plays a vital role in enhancing mechanical properties of metal-composite alongside with increasing the temperature during sintering.

4.2 Phase analysis of the metal-composite

The X-rays diffractographs of sintered "Sample ß" (Yttrium free) fabricated at 950 °C, 1050 °C, 1150 °C, 1250 °C is shown in **figure 3.** From X-rays diffractographs three significant peaks were identified. These spectrums indicates that the sintered samples are polycrystalline with clear distinctive identical peak. The prominent peak observed are indexed for the cubic structure of nickel (Ni)[15]. The diffraction peaks can only be formed when the atoms well arranged, and reflection obtained from the planes. The presence of different phase could be established by diffraction analysis due to the degree of closeness towards the properties of crystallinity[16]. X-rays diffractions only give accurate result for crystalline phases. From figure 3 the most prominent peak appeared at 2θ=42°, 50° and 76° with presence of ZrO_2, Cr-Ni and Ni respectively. While at higher sintering temperature of 1150 °C and 1250 °C formation of Ni and Zr takes place 2θ=42° and 2θ=76° correspondingly. After observing the intensity of peaks, it could be revealed that presence of Ni is high at 950 °C sintering temperature and further decreases as the temperature rises. Figure 4 shows the X-rays diffractographs of sintered Sample ý" (Yttrium mixed) fabricated at 950 °C, 1050 °C, 1150 °C, 1250 °C. Here it wasobserved the occurrence of four significant peaks which were at 2θ=26° yttrium with ZrO_2, 2θ=41° ZrO_2, 2θ=48° Cr, and 2θ=75° Ni.

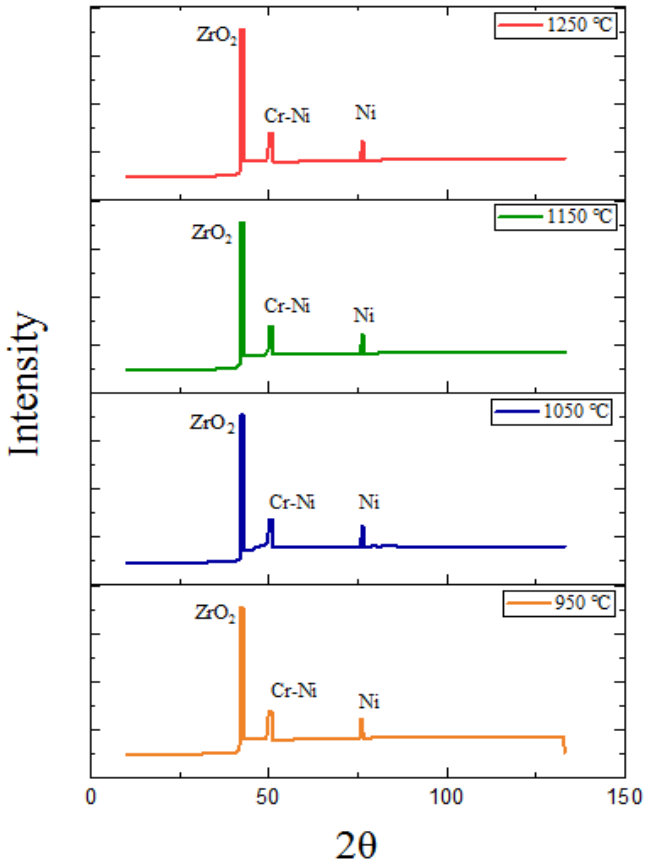

Figure 3. X-rays Diffraction result of sintered "Sample ß" (Yttrium free) fabricated at 950 °C, 1050 °C, 1150 °C, 1250 °C sintering temperatures.

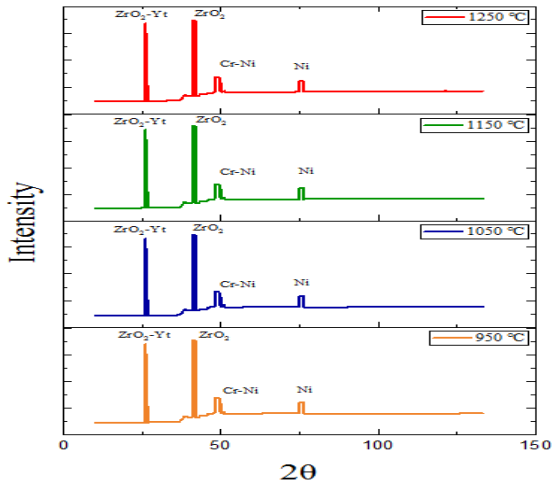

Figure 4. X-rays Diffraction result of sintered Sample ý" (Yttrium mixed) fabricated at 950 °C, 1050 °C, 1150 °C, 1250 °C sintering temperatures.

From figure 3 and figure 4 it was observed clearly that through mixing of yttrium in ZrO_2-Cr-Ni metal-composite the intensity has been increased significantly. The formation of other solid solution occurred which helps in enhancing the overall structural properties of yttrium mixed metal-composite. After sintering process, the shape of ZrO_2 reshaped into tetragonal structure which was monoclinic in shape previously. This transformation can only be possible through mixing of yttrium in ZrO_2-Cr-Ni metal-composite. With the advancement in sintering temperatures the peak of BCC-Cr disappeared and only FCC-Ni appeared, which shows that adding of yttrium in ZrO_2-Cr-Ni metal- composite completely dissolves the BCC-Cr into FCC-Ni to form Cr-Ni homogenous mixture in ZrO_2- Cr-Ni-yt based metal-composite. The phase transformation enhances the melting point and hardness, which improves the overall mechanical properties of metal-composite.

4.3 Hardness of the metal-composite

Figure 5 shows the Vickers Hardness properties as the function of sintering temperature of sintered composites of "Sample ý" (Yttrium mixed) and "Sample ß" (Yttrium free). Comparing the Vickers hardness values of both the samples it was revealed that at 1250 °C the Sample ß" (Yttrium free) has 447 HV and the "Sample ý" (Yttrium mixed) has 461 HV. It was observed that at the lowest temperature i.e., 950 °C the metal-composite have hardness 417 HV and as the sintering temperature rises the value of hardness increases too. However, this relationship has already been used in the previous literatures for the other ceramics or composites which proves here a valid result for this research[17]. Yttrium addition in ZrO_2-Cr-Ni metal- composite enhances the hardness and thus overall mechanical properties.

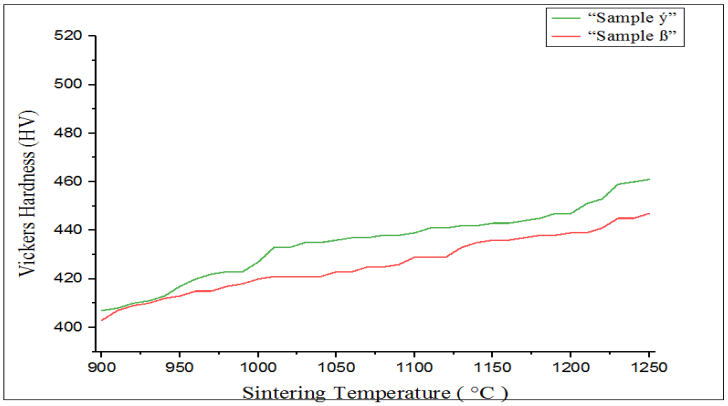

Figure 5. Vickers Hardness result as of sintered composites of "Sample ý" (Yttrium mixed) and "Sample ß" (Yttrium free) at various sintering temperatures.

4.4 Bending Strength of the metal-composite.

Figure 6 illustrates the variation of sintered "Sample ý" (Yttrium mixed) and "Sample ß" (Yttrium free) at different sintering temperatures of 950 °C, 1050 °C, 1150 °C, 1250 °C along with porosity percentage. It was observed, the addition of yttrium in ZrO_2-Cr-Ni metal-composite increases the bending strength which attain a maximum value at 1250 °C of 915 MPa ("Sample ý" (Yttrium mixed)). But at 1150 °C it was seen that the value of bending strength of both the samples were almost resembles the same i.e., "Sample ý" (Yttrium mixed) having 686 MPa and "Sample ß" (Yttrium free) having 667 MPa. Also, it was seen that at this value the rate of porosity also decreases quite swiftly.

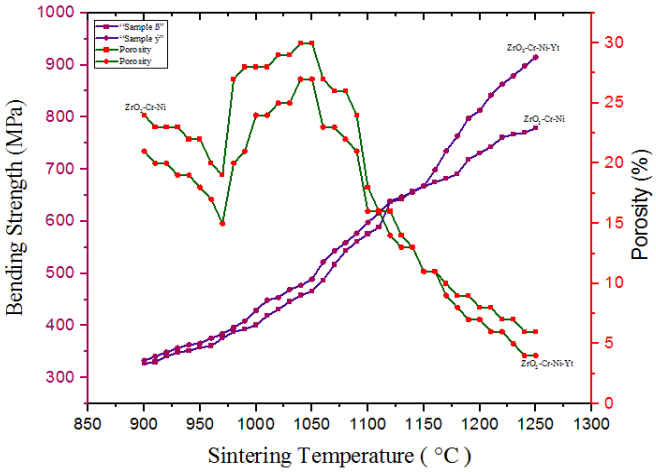

Figure 6. Bending Strength result of "Sample ý" (Yttrium mixed) and "Sample ß" (Yttrium free) at different sintering temperatures of 950 °C, 1050 °C, 1150 °C, 1250 °C with the rate of porosity variations.

The densification of the individual molecular structure of ZrO_2, Cr, Ni and Yt was the reason behind the existence of close value of bending strength at sintering temperature of 1150 °C in both the samples, but in case of yttrium mixed sample it was slightly elevated. This would involve the utilization of latent heat which would breaks molecular bonds existence in between the ZrO_2 atoms. But suddenly after the completion of sintering process at 1250 °C the bending strength of "Sample ý" (Yttrium mixed) resembles a value of 915 MPa. The most prominent reason behind this whole process is the rate of porosity which would be analyzed through understanding the concept of atomic radii of individual element used in this metal-composite, which were Zr, Cr, Ni and Yt. The atomic radius of Zr-0.160 nm, Cr-0.130 nm, Ni-0.124 nm and Yt-2.27 Å. It was observed that Zr, Cr, and Ni were having almost equal range of radius values. When these all elements were mixed and prepared for sintering, then occurrence of a gap existed i.e., inter-atomic spaces which was enough for fitting of yttrium atoms. Addition of yttrium made ZrO_2-Cr-Ni metal-composite more densely packed. These atoms of yttrium now fuse into ZrO_2-Cr-Ni during sintering process with little more amount of energy in the same value of sintering temperature as compared with "Sample ß" (Yttrium free. Afterward it was observed, the sudden increase in the value of bending strength simultaneously with the propagation of sintering temperatures and decrease in the rate of porosity instantly. It suggests that the addition of yttrium have enhanced the bending strength.

IV. CONCLUSION

The incorporation of yttrium in the ZrO_2-Cr-Ni composite has resulted in a refined microstructure, with Yttrium oxide (Y_2O_3) acting as a grain boundary stabilizer and hindering the growth of crystalline grains. This refinement leads to a reduction in porosity and defects, resulting in increased mechanical strength and resistance to deformation. Furthermore, the formation of a stable Y_2O_3 phase significantly enhances the composite's high-temperature performance and corrosion resistance, making it suitable for a wide range of demanding engineering applications. The formation of Y_2O_3 dispersion within the composite matrix contributes to grain refinement and improved grain boundary cohesion, leading to increased toughness and durability.

The CIP has enhanced the packing strength of the ZrO_2-Cr-Ni-Yt metal-composite which, would be observed for during the microstructural scanning of the sample which suggests, the yttrium would be an ideal substituent to fill the dislocations formed between the ZrO_2, Cr and Ni atoms.

The Vickers hardness values of ZrO_2-Cr-Ni metal-composite were enhanced after the addition of

yttrium in the small percentage. However, at lower sintering temperatures the Vickers hardness values for both the samples are same to some extent but later at higher sintering temperatures the enhanced hardness values could be visualized clearly.

The bending strength values were lowered at low sintering temperatures and in between 1100 °C to 1150 °C the bending strength values of sample "Sample ß" (Yttrium free) strike higher values than "Sample ý" (Yttrium mixed), which shows the starting of densification process but as the densification completed later, the differences could be observed of the enhancement in the bending strengths due to yttrium addition.

The present study has demonstrated that careful optimization of the Yt content with respect to the compositional percentages of Zirconia oxide, Nickel, and Chromium which, allows tailoring the composite's mechanical properties to meet specific application requirements. However, it is essential to strike a balance between Yt content and other alloying elements to avoid any negative impacts on overall mechanical performance.

As the demand for advanced materials with superior mechanical characteristics continues to grow, the ZrO_2-Cr-Ni-Yt metal-composite holds great promise as a viable metal-composite for various engineering and industrial applications, such as aerospace, automotive, structural components, and biomedical purposes.

Furthermore, the synergistic interaction between yttrium and the existing alloying elements facilitates the development of a more stable microstructure, reducing the occurrence of defects and promoting consistent mechanical performance.

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