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Tensile strength and Fractography analysis of Ti6Al7Nb with 8YSZ coatings

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There are more than 700 tribal communities spread in a majority of the states in India. They live in interior forests, remote areas or on hilltops with difficult terrain which are difficult to access. This research focuses on the growth of higher education within the framework of preferential treatment and supportive measures for the benefit of different social groups, namely, the Scheduled Castes, the Scheduled Tribes, minorities and women. The study also reviews the policies which influence the mode of functioning of higher education. The policies are built on the framework of equity, equality and mainstreaming. The affirmative policy for the scheduled tribes' builds equity and mainstreaming which leads to policies on equality. In our Indian society which is multi-cultural, multi-linguistic and multi-ethnic there are many parameters such as gender, caste, and region are vital in defining access to higher education. Lastly, the educational policies and programmes are unable to include the complex social reality within a single framework and are, therefore, unable to bridge the gap between policy and practice.
Keywords: Higher Education, Adivasis, PVTGs, Scheduled Tribes

Introduction

Contemporary traumatology and orthopedics are consistently exploring for advanced biomaterials aiming at deducing the osteosynthesis time and producing biologically, mechanically compatible implants for replacing lost or diseased biological structures for the reinvigorate the damaged bone tissue [1-5]. Titanium alloys have distinct amalgamation of high corrosion resistance and low elastic modulus with good bio-compatibility which enabled to be extensively used as implants for heart halves, hip-knee replacement etc [3,14].

It is critical that the material considered is bio-compatible and hypo-allergenic, with high wear and corrosion resistance, osseo-integration and non-cytotoxicity to prevent revision of surgeries also it is essential to have high strength, resistant to fatigue [6,7].

Ti6Al4V is the most widely used implant material but it due to the presence of vanadium which pose a large risk of long-term health problems, e.g., Alzheimer's disease, osteomalacid and supplementary neurological conditions. Niobium has replaced the presence of Vanadium which has no biologicals risks involved. Among the Va group, V and Nb belong to Va group. They are amorphous and show similar characteristics mainly the effect to stabilize β phase in Ti-V and Ti-Nb binary systems as it is important to provide α +β two phase structure to the alloys [8-10] Therefore, niobium can be used as a ternary element to produce the desirable implant [11-13].

It is evident from past studies; these alloys possess inferior tribological properties which are due to inadequate hardness along with elevated and unsteady coefficient of friction which will reduce the lifespan of the components in biomedical applications [11-15] there is a need to improve the tribological properties of these alloys, surface modifications should be integrated by using thermal barrier coatings (TBCs) [19-21,27].

Among the TBCs, plasma spraying technique is exceptionally efficient commercial process utilized to deposit materials. It is an uncomplicated to operate in which the fresh powder is injected into the plasma jet carrier gas gun which is heated and accelerated particles in-flight touch onto the substrate succeeded by rapid spreading and solidification [22-24]. A typical thermal barrier coating (TBC) comprised of double layer over a super alloy substrate: bond coat (BC) and top coat [25-27]. A metallic bond coat and ceramic top coat of Yttrium stabilized Tetragonal Zirconia Polycrystalline (YTZP or YSZ), in which (8%) yttrium oxide used as additive stabilizes (92%) zirconium oxide giving rise to 8YSZ (fully stabilized zirconia oxide) which is very suitable as anti-wear coating on titanium alloys at high level temperatures for its stunted thermal conductivity and adequate mechanical properties providing superior fracture resistance [28-31].

In this work, 8YSZ powder is deposited using thermal barrier (plasma spraying) coating on Ti6Al7Nb dog bone shaped and to study its effect on the tensile properties of the substrate and coated samples. Fractography analysis is studied to understand the mode of tensile fracture.

2. Material and Method

2.1 Material Characterization

2.1.1 8 mol% Yttrium stabilized Zirconia (8YSZ)

Yttria Stabilized Tetragonal Polycrystalline Zirconia (YTZP) is the strongest ceramic material so far according to ST material solution. In the present study 8 mol% Yttrium stabilized Zirconia (8YSZ) acts the top coat with NiCrAlY as the bond coat on the substrate metal. 8YSZ concocts of 8% Yttrium oxide (yttria) is used to stabilize 92% Zirconium oxide (zirconia). The powder is deposited at various coating thicknesses on the substrate such as 100 μm, 200 μm, 300 μm, 400μm.

The morphologies of 8YSZ with NiCrAlY as the bondcoat were confirmed using JSM-1005 Field Emission Scanning Electron Microscopy (FESEM) and the chemical composition of the powders were acquired through Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscopy (EDS), Tescan vega 3, LMU version and the phases were analysed using a ST-EQ-167 X-Ray Diffraction (XRD) with the Cu-Kα radiation (λ=1.54060 Å).

2.1.2 Ti6Al7Nb

Ti6Al7Nb is used as the substrate metal with NiCrAlY as the bond coat and 8mol% Yttrium Stabilized Zirconia (8YSZ) as the top coat deposited using plasma spraying process. Dog-bone specimens of 25mm as gauge length, 6.9mm as thickness and 6.63mm width are cut using Electronica Maxicut 434 Wire Electric Discharge Machining (WEDM) for tensile testing as per ASTM E-8 standard as shown in Fig.1 a) specimen prepared according to ASTM E8, b) specimens after being cut using WEDM. Material characterization was carried out using Energy Dispersive X-Ray Spectroscopy (EDS) for the base material. Microscopic observations were carried out using JSM-1005 Field Emission Scanning Electron Microscopy (FESEM).

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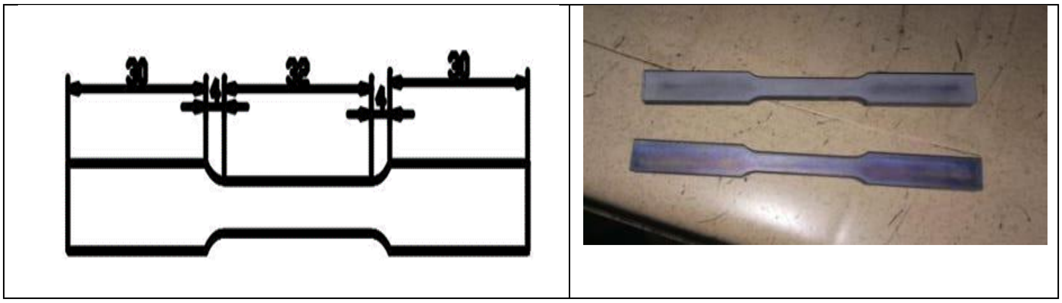


Fig.1 Specimens prepared for tensile testing cut according to ASTM E-8 using Wire cut EDM

2.1.3 Plasma Spraying

The area is cleaned with dry air to eliminate the residues prior to which the surface of the substrate undergoes grit blasting using aluminium grit to improve the bonding strength of coating. NiCrAlY (50-100μm) is used to deposit as the bond coat by Air plasma spraying technique at desired thicknesses 100 μm, 200 μm, 300 μm and 400 μm respectively followed by 92% ZrO_2, 8%Y_2O_3 as the top coat.

2.2 Hardness

Macro hardness test is carried out using Rockwell C with diamond indenter. 60KgF load has been used with dwell period of 15 seconds and five indentations were made on each of base and coated material (100 μm, 200 μm, 300 μm, 400 μm). An average of the five readings are obtained for every specimen considered.

2.3 Tensile testing and Fractography analysis

Mechanical properties were determined through the tensile testing of the specimens at room temperature on Servo-Hydraulic, INSTRON 8501 to conduct the test. The transverse speed was 1mm/min. Fractography analysis was carried out to study the type of fractured occurred using SEM.

3.Results and Discussion

3.1 morphologies of metal and powder

3.1.1 Ti6Al7Nb

Fig.2.shows the morphology of the substrate (Ti6Al7Nb). From the EDS analysis of Fig.2 and table.1 Ti is the highest peak which is followed by other elements such as Al, Nb with the presence of oxygen and carbon.

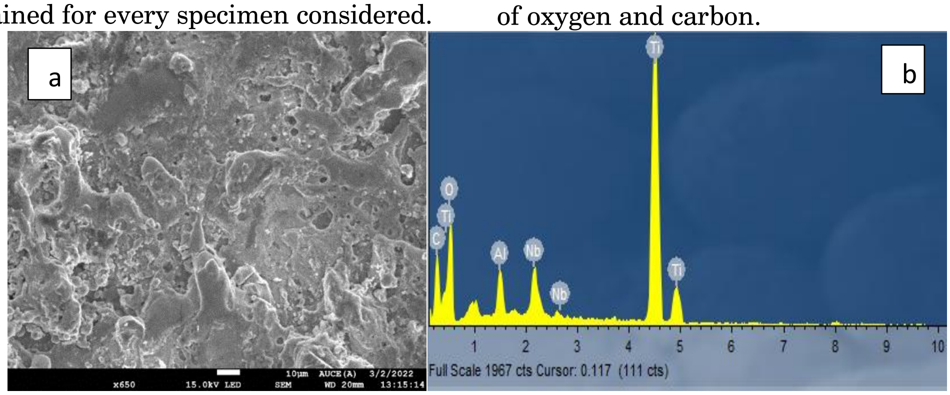


Fig.2. FESEM and EDS analysis of Ti6Al7Nb (substrate)

Table.1 Weight and atomic percentage of elements of Ti6Al7Nb

S.No	Element	Weight %	Atomic %
1	O	36.68	53.26
2	C	11.35	21.95
3	Ti	43.76	2.48
4	Al	2.48	2.13
5	Nb	5.73	1.43

3.1.2 8 Mol% Yttrium Stabilized Tetragonal Polycrystalline Zirconia (8YSZ) powder- top coat

Fig.3. a, b, c) shows the surface morphology of 8 mol% Yttrium Stabilized Tetragonal Polycrystalline Zirconia (8YSZ) powder. From Fig.3. c). The XRD analysis revealed the characteristics peaks for YSZ powder material in the spectra at 30.1569° attributed to tetragonal ZrO_2. The formation of tetragonal phase is due to the rapid solidification and rapid cooling of feedstock particles on the substrate. The 8YSZ powder was mainly composed of ZrO_2 and Y_2O_3, along with other trace elements. Perumal *et al.* [2014] the 8YSZ powder exhibits porous spherical morphology with non-uniform particle size. The powder composed of regularly shaped formations of different sizes with rounded features which are uniformly scattered with tiny pores and even texture on the surface without being agglomeration.

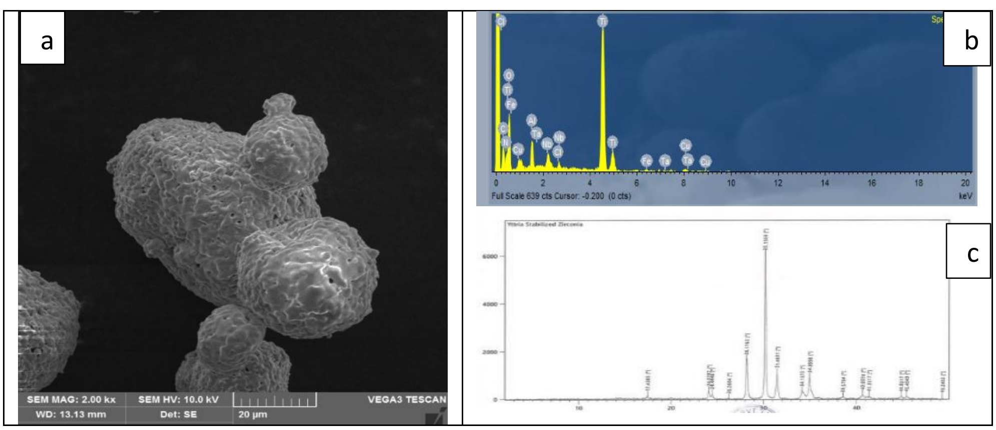


Fig.3. SEM, EDS, XRD analysis of 8YSZ POWDER (top coat)

Table.2 Weight and atomic percentage of elements in YSZ

S.No	Element	Weight %	Atomic %
1	C	20.9.	45.09
2	O	24.35	39.43
3	Hf	0.72	0.10
4	Y	5.59	1.63
5	Zr	48.43	13.75

3.1.3 NiCrAlY- Bond coat

Fig.4. shows the SEM micrographs and SEM-EDS analysis of bondcoat material (NiCrAlY) with Ni being the highest peak and the followed by Cr, Al

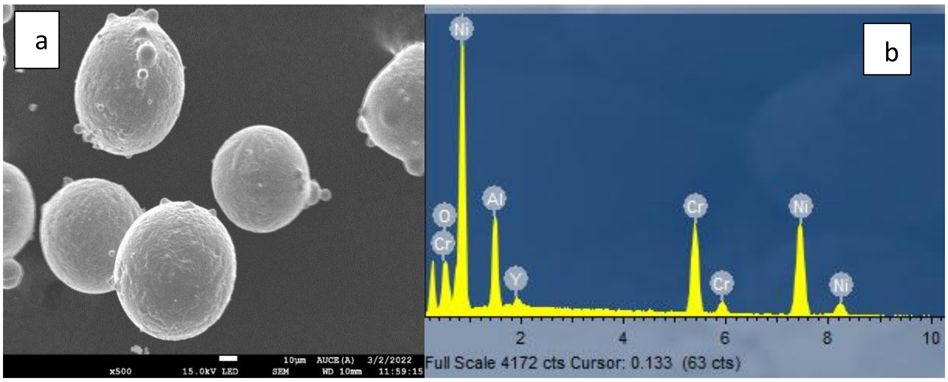


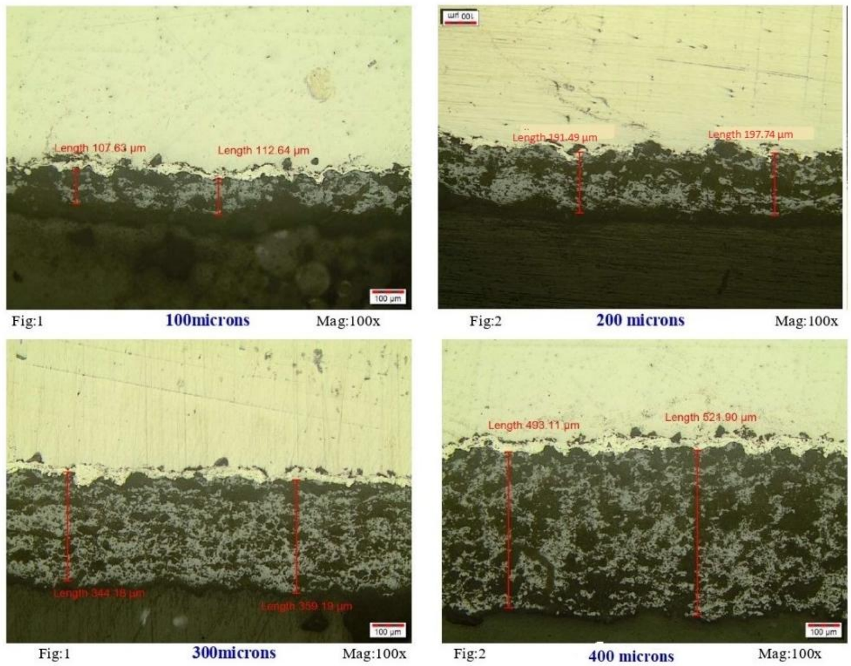
Fig.4. FESEM, EDS analysis of NiCrAlY (bondcoat)

Table.3 Weight and atomic percentage of elements of bond coat- NiCrAlY

S.No	Element	Weight %	Atomic %
1	Ni	60.72	48.36
2	Cr	23.24	20.90
3	Al	9.25	16.04
4	Y	2.14	1.13
5	O	4.65	13.58

3.1.4 Cross sectional thickness of 8YSZ coating of different thickness

Fig.5. Shows the cross section of microstructure of 8YSZ coatings deposited on Ti6Al7Nb substrate. Micrograph has been captured in ambient room temperature The coating cross sections were composed of 8YSZ coating as the top layer, NiCrAlY bond coat as the intermediate layer and Ti6Al7Nb as the substrate.The coating thickness was meaured as per IS:3203 and shown in table:4.



Powder Coated Pin
Substrate: Ti6Al7Nb, Coating Powder : YTZP

Fig.5. Cross-section microstructure of 8YSZ coatings deposited with varying thicknesses

Table.4 Coating thickness in μm

Samples	Experimental (plasma spraying)	Measured value (optical microscope)
Ti6Al7Nb (substrate) + NiCrAlY (bond coat 50-100 μm) + 8YSZ (top layer)	100	107-112
	200	191-197
	300	344-359
	400	493-521

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Optical microscope was used to measure the cross-sectional thickness of the coated specimens. Fig.5. and table.4 shows the experimental and range of measured values of the coating which has NiCrAlY as the bond coat with a thickness of 50-100 μm.

3.2 Macro hardness

Hardness of the substrate is observed to be 48 HRC and the value of microhardness increased from base material to the coated specimens. The average hardness of the coated specimens of different thickness was observed to be 54 HRC.

3.3 Tensile testing and fractography analysis

From table.5.and Fig.6 it was to be observed that there is a sharp rise in the curve from substrate to the 300 microns coating thickness, with almost 40 % of increase in the UTS values. It is observed that ultimate tensile strength was increasing from 100 μm up to 300 μm and decreased (400 μm) thereafter.

Table.5 Mechanical properties (Ultimate tensile strength, yield strength and % elongation) of Ti6Al7Nb and 8YSZ coated Ti6Al7Nb

S.No	Specimen/coating thickness	Ultimate tensile strength (MPa)	Yield strength (MPa)	% Elongation
1	Substrate (0% coating)	725+_5	l685	5.6+_0.3
2	100 microns	798+_9	745	6.4+_0.7
3	200 microns	997+_4	950	7.3+_0.4
4	300 microns	1335+_12	1298	3.3+_0.3
5	400 microns	1148+_11	1120	3.5+_0.6

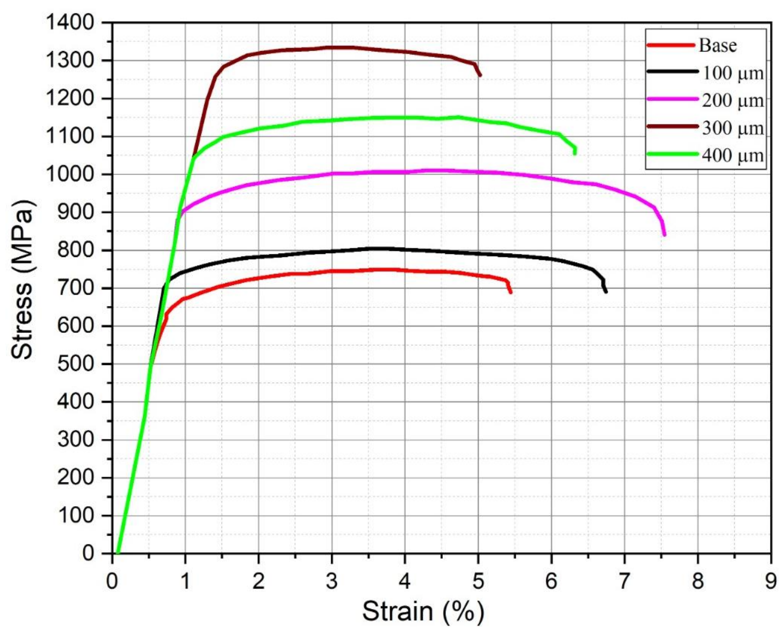

Fig. 6. Stress vs strain% of base material and coated samples with different thicknesses

Fractography analysis was carried out using Scanning electron microscope. SEM micrographs of substrate and 8YSZ coated specimens with varying coating thickness from 100 microns to 400microns are analyzed. The dimple formation in the Fig.7. indicates that the fracture occurred is in ductile manner. When a surface is fractured, micro voids are created due to the separation of material under the external tensile forces. These micro voids grow into small, shallow dimples. These voids grow during plastic flow of the material and eventually coalesce into larger voids. In the final stages of the failure, these voids separate at the fracture surface and undergo significant necking, which leads to a characteristic dimpled texture. These studies have been similar to the reports of [17,18].

From the findings [8,9,11]it has been found that fracture resistance of Ti6Al7Nb alloy is superior to that of the other Ti alloy. The deformability and fracture resistance of Ti6Al7Nb is more amenable to the hit working and thermo-mechanical process involved in the fabrication of biomedical implant components.

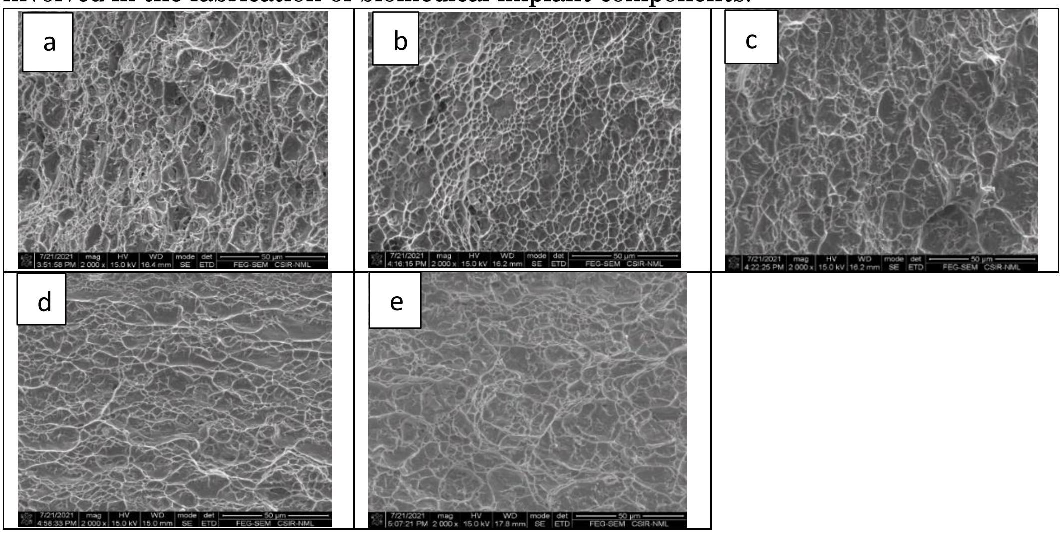

Fig.7. Dimple formation in SEM micrographs of a) Substrate and 8YSZ coated Ti6Al7Nb b) 100 microns, c) 200 microns. d) 300 microns, e) 400 microns coating thickness

YTZP polycrystalline material and the most significant influence on the mechanical properties is the tetragonal crystal structure. Zirconia is commonly alloyed with small amounts of a metal oxide such as Yttrium oxide (Y203). When a crack develops, an associated stress field around the crack also forms. This can be enough to induce the transformation of one crystal structure to another which has an approximate 3% volume expansion. This means that when a crack begins to propagate in YTZP, the crystal transformation due to the applied stress results in a resistance to further crack growth. YTZP belongs to a unique family of transformation-toughened ceramics that all have this toughening phenomenon at work within their microstructures.

YTZP exhibits a trait called transformation toughening which allows it to resist crack propagation. Applied stress, magnified by the stress concentration at a crack tip, can cause the tetragonal phase to convert to monoclinic, with the associated volume expansion. This phase transformation can then put the crack into compression, retarding its growth, and enhancing the fracture toughness. This mechanism significantly extends the reliability and lifetime of products made with stabilized zirconia. YTZP is well suited to replacing metals due to its extremely high strength and toughness, it also offers far higher resistance to chemicals and superior erosion resistance [15,16].

In order to determine the optimum formability of implants and to ensure the mechanical integrity of the finished components it is necessary to understand the mechanical deformation behaviour of Ti6aAl7Nb alloy and the methods to reduce or overcome these deformation so as to increase the lifespan of the implant in the human body.

4. Conclusion

1.300 μm coated sample sample shows tensile strength as 1335MPa which is 45% greater than the substrate material. Ultimate tensile strength observed to increase from substrate to coated till 300 μm coating thickness further it was decreased.

2.Ductile behavior is confirmed in the fracture surface of Ti6Al7Nb due to the presence of trans granular facets.

3.Fatigue striations and forced ruptured surfaces are observed on the fatigue fractured surfaces showing dimple formations.

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