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Research Article

A prospective analysis of mechanical properties of different Ti-Nb alloy compositions: A review

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Abstract: Powder metallurgy is emerging day by day as a concrete solution to the new age scientific problem. Every metal has its own characteristics and limitations. Powder metallurgy confluences the good characteristics of different metals into one product, but requires a correct combination of various sub-processes associated with main process. Powder metallurgy conquers the power of 4 P,s i.e. Precision as producing near net shape, Performance as fast and consistent , Productivity as higher output and Price as low considering lesser secondary operation needed. Some important mechanical properties of the different Ti-Nb alloys are analyzed in relation to the human implants. This paper reviews different sub processes of powder metallurgy and their combination for the biomedical application of different power metallurgy products. Papers also describe some advancement in manufacturing techniques and powder metallurgy sub processes that enhance the behavior of materials for human implants.
Keywords: Powder Metallurgy, Ti-Nb, Biomaterials.

INTRODUCTION

Human life is the most precious things and biomaterials have emerged as a boom to those defected. The field of biomaterial has become an area for providing and depicting the quality and longevity to human life. [1].

Powder metallurgy has many distinct advantages in each of the field it is used but considering biomaterials it has to deals with human life. There are certain constraints associated with materials when used as human implant such as toxicity, morphology grain growth, stress shielding, stability, cost etc.

The biomaterials used human implants should be nearly characterized or properties very similar as possible to the bone for proper stability and capability to the human cells and tissue or the body should happily and easily accept that material. The effect of living body environment on the mechanical properties is also very important to understand [2].

Many metals and their alloys have been used as biomaterials till date such as varies grades of stainless steel [3], cobalt- chromium and titanium alloys [4]. Titanium and its alloys are used extensively in implantable medical applications [5]. Titanium and its alloys have showed great deal of biocompatibility, bio-adhesion, bio-functioning and corrosion resistance [6].

Commercially pure Ti has a sufficiently high mechanical properties as ultimate tensile strength (UTS) (785 MPa) and modulus of elasticity € (105 GPa). These were further enhanced by alloying it with Al and V. Ti 6Al4V also famously known as Ti64 has the UTS as 970 MPa and the E 110. Ti64 showed a great biocompatibility and strength and was widely accepted as an alloy for joint replacement and implants for a long time but some recent result shows the level of cytotoxicity in the use of alloy [7]. Also the E as compared to the human bone (10-40 GPa) was too high which causes stress shielding effect and results in joint loosening when subjected to cyclic loading.

The problem of this cytotoxicity and stress shielding has been overcome by the use of Niobium (Nb). Various alloys has been developed using Nb with Ti and other materials like Mo, Ta, Zr, Sn, Hf which are Al and V free. These metals can be characterized on the basis of α & β phase materials. Nb has emerged as a strong β phase stabilizer material that efficiently transforms the phase from α to β during sintering [8]. Zr is considered to be a neutral element but shows some positive β transformation when combined with Nb [1]. Zr also helps in improving shape memory effect, super elasticity [9], enhancing corrosion resistance, promoting solid solution hardening [10].

A conventional powder metallurgy process consists of four basic sub processes namely powder production, blending or mixing, compaction and sintering. Powder production, as being the primary process, affect adversely on the following process. Table 1 describes the different processes under the blended elemental and prealloyed powder approach along with their process temperature and size & shape of powder particle produced. So a great care must be taken to choose the powder producing process.

Table 1: Different Titanium Powder Production Techniques Blended Elemental (BE) & Pre Alloyed Powder (PAP) Approach

Process Name	Approach	Phase Structure	Process Temperature (˚C)	Grain Size	Shape
Kroll Process	BE	Ti Sponge	1040	45-180	Irregular, Porous
HDH	PAP	Ti 5-Grade	400	50-300	Angular
PREP	PAP	Ti 5-Grade	>10000	100-300	Spherical
TGA	PAP	CP Ti, α,β Ti	>10000	50-350	Spherical
PA	PAP	CP Ti	>10000	0-200	Spherical

HDH-Hydride Dehydride, PREP- Plasma rotating electrode process, TGA- Thermal gas atomization, PA- Plasma atomization

In blending or mixing of the powder particles for different alloys, binders and additives are also added. Sintering is done post compacting at a temperature ranging from 70-90% of the melting point of the parent metals for the time period sufficient to allow proper bonding. The grains are restrained during sintering with Nb [11]. Some advance processes like two step foaming [8] and adding additives like wax or resin like PMMA [12] which can later be removed and results in variable porosity parts as required. The porous parts helps in better cell tissue growth and are having low E and density of the order of a human bone.

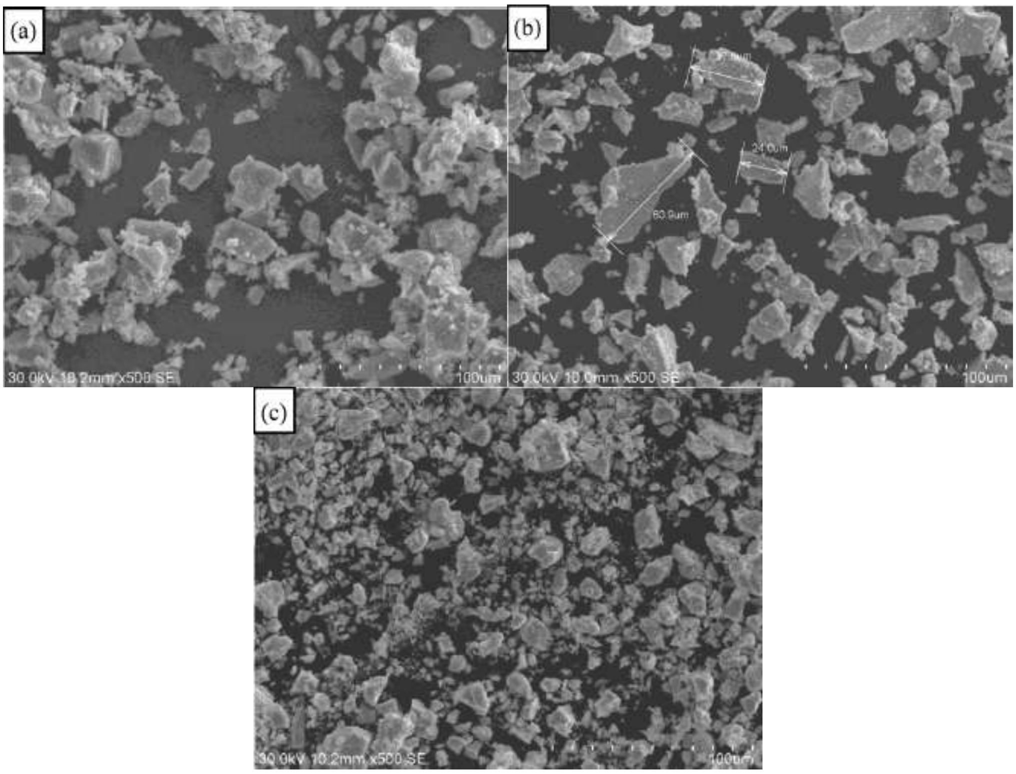
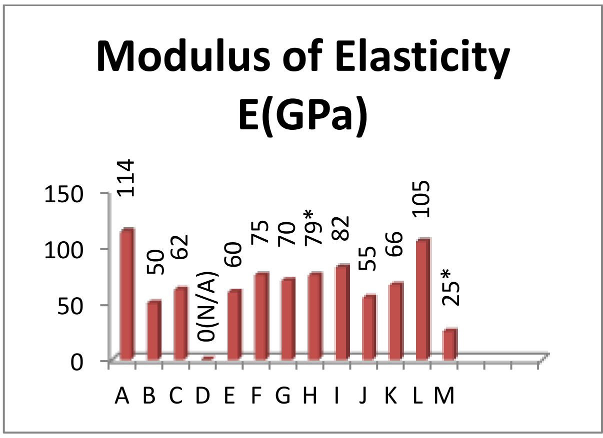
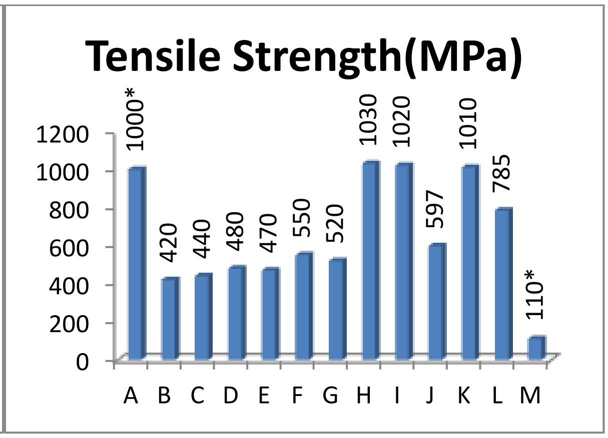


Fig 1: SEM Images of Ti (a), Nb(b) & Zr (c) metals

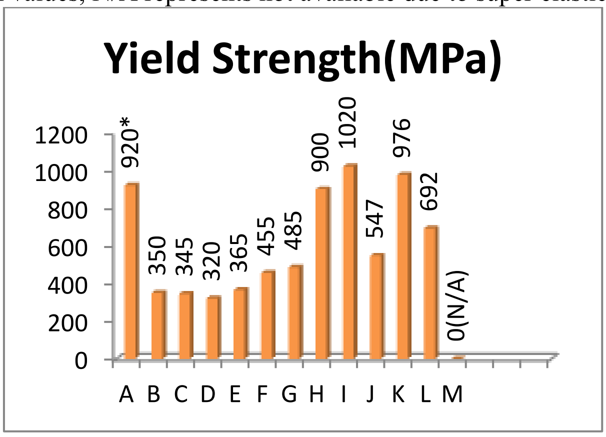
Table 2: Mechanical Properties of Different Ti-Nb alloys[13, 14]

Alloys	Phase Composition	Sym bols	Tensile Strength(MPa)	Modulus of Elasticity E(GPa)	Yield Strength(MPa)
Ti-6Al-7Nb	α+β	A	900-1050	114	880-950
Ti-26Nb	B	B	420	50	350
Ti-24Nb-2Zr	B	C	440	62	345
Ti-22Nb-4Zr(Super Elastic)	B	D	480	Super-elastic	320
Ti-20Nb-6Zr	B	E	470	60	365
Ti-18Nb-8Zr	B	F	550	75	455
Ti-16Nb-10Zr	B	G	520	70	485
Ti-13Nb-13Zr	B	H	1030	69—79	900
Ti-15Mo-3Nb	B	I	1020	82	1020
Ti-35.3Nb-5.1Ta-7.1Zr	Metastable β	J	597	55	547
Ti-35.3Nb-5.1Ta-7.1Zr-0.40O	Metastable β	K	1010	66	976
CP Ti	A	L	785	105	692
Bone	--	M	90—140	10—40	--





'* represents mean values, N/A represents not available due to super elastic nature of material



Mechanical properties of Ti-Nb alloys

The mechanical properties are a cursor which shows the strength of a material or alloys in the differentially loading conditions. There are various measures of mechanical properties such as UTS, yield Strength (YS), elongation, surface finish, fatigue strength, fracture toughness, hardness etc. Each of these properties has its own effect and nature on the real working conditions of the alloy. But in human implants the most needed properties are UTS as it define the strength of the material when loaded, YS as it defines the point at which the material will start deforming plastically and E as it shows the tensile elasticity. Among the mechanical biocompatibility, E has been given considerable attention [5].The properties, UTS, YS and the E of the various Ti-Nb alloys, which has been manufactured and are in use, are shown in the table 2.

In UTS it is evident from the figure 1 that the Ti-13Nb-13Zr is having the highest value (1030 MPa) which is a β phase material. It is also evident that as the value of Zr is increased in relevance to Nb, keeping the proportion of the alloy same the value of UTS increases linearly. Also the Ti-15Mo-3Nb and TNTZ also shows sufficiently high values of ultimate tensile strength in comparison of bone which is (90-140 MPa). The YS (figure 2) shows the similar behavior as in the case of UTS but the exception is the Ti-22Nb-4Zr which is a super elastic material. The highest value is of the order of 1020 MPa in case of Ti-15Mo-3Nb.

The E is also an important quality and the approach has been to develop an alloy having nearly same E as that of a human bone. Most the alloys developed so far has the much higher value of E as compared to human bone. Ti-26Nb has the lowest and a closer value (50 GPa) which is closest to the bone (10-40 GPa). The value of E should be closer to the human bone to create an acceptable environment in the body for the proper cell tissue growth and diffusion of implant in to the body. A flash thermal treatment has also been done nowadays to enhance the super elastic performance of Ti-Nb alloys [15]. Also some newer manufacturing techniques such as additive layer manufacturing and metal injection molding has been developed to produce more porous structure of Ti alloys which is essential for biomaterials [16]. Surface engineering also play an important role in improving the mechanical properties of Ti alloys [1].

CONCLUSIONS

Following conclusions may be drawn from the above study

1. Ultimate tensile strength of the Ti-Nb alloys prepared till date ranges between 420-1030 MPa. However the varying proportions of additives and composition of alloy affects the UTS considerably.
2. The Yield strength ranges from 320-1020 MPa. But the table shows the due to the super elastic behavior of Ti-22Nb-4Zr the value recorded was low, unlike the pattern it should follow by varying proportions of Nb and Zr.
3. The E ranges from 50-110 GPa which is not far from the value from human bone (10-40 GPa) for some alloys. Similar value of E is desirable to achieve the greater biocompatibility and cell tissue growth.

The alloys should be made with mechanical properties similar to that of natural human bone along with the use of materials that promote biocompatibility and cell tissue growth. Various other compositions can be made that are less chemically active to promote stability and corrosion resistance. Also the use of advanced manufacturing techniques such as ALM and MIM or the improvement in existing powder manufacturing techniques to obtain good mechanical and biomedical properties is recommended.

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