In the present study, titanium-based copper alloy foams were synthesized using acrawax as a space holder through powder metallurgy route. The effects of distinct pore size range and Cu content on the microstructural features, density, compressive and flexural behaviour were investigated. Results show that the amount of microporosity generated was more in case of foams with coarser pores than finer ones and also it increased with increase in Cu content. The presence of fine pores and lower amount of Cu led to generation of minimal amount of microporosity; resulting into greater relative density of Ti-Cu foams. The plastic collapse stress, plateau stress and bending strength of Ti-Cu foams decreased while densification strain increased with increase in Cu content. The maximum value of plastic collapse stress is reported for Ti-3Cu foam with fine pores. The plateau strength and bending strength of Ti-3Cu foam with fine pores was found to be higher than that of Pure Ti foams and was found to be the most optimized in terms of the characteristic features. The higher values of relative density, plateau and bending strength of Ti-3Cu foams makes them more preferable over pure Ti foams for implants applications.

1. Introduction

In the past few decades, metal foams have gained a lot of attention in the research community due to their various unique properties, such as excellent physical, mechanical, acoustic, thermal, and biological properties. Their properties can be tailored to fit the required applications [1]. Such properties of metal foams make them suitable to be used in the field of lightweight structures, sandwich cores, vibration control, acoustic absorption, heat exchangers, bio-implants, etc. [1–5]. Among metal foams, titanium is one of the most utilised metals in the field of engineering and biomedical applications. In structural applications, titanium foams are very popular for the manufacturing of sandwich core for aircrafts and submarines [6–8]. It is corrosion resistant, bio-compatible and possesses tensile strength comparable to that of various grades of steel which makes it suitable to be used as implants [9]. Porous titanium with open cellular structure can also promote ingrowth of tissues and transport of body fluids [10–12]. Porosity and pores structure can be adjusted to achieve desired strength, modulus comparable to bone so that there is no aseptic loosening of implant [2]. Also, there is reduction in stress concentration due to distribution of load over a large surface area of porous implant attached with bones [13]. The mismatch in the elastic modulus of bone and implants leads to stress shielding effect i.e. insufficient loading of bone which ultimately results into slow bone remodelling, healing and increased porosity [14–16].

Titanium and its alloys as compared to steel (200 GPa), CoCrMo alloys (200 GPa) has relatively lower value of elastic modulus (90–110 GPa) which make them preferable over other alloy systems to be used as bio-implants since the elastic modulus of human bone is in the range of 10–30 GPa [17–21]. Among Ti alloys, Ti6Al4V is very popular alloy to be utilised as bio-implant material [22]. The release of aluminium and vanadium ions in the blood causes very harmful effects on human health while using Ti6Al4V as implant material [23, 24].
The number of alloying elements such as Al, V, Ni and Co with Ti were found to be cytotoxic in nature while utilising them as implants within human body [25–27].

In spite of having several merits, titanium has its own limitation of processing through liquid metallurgy route due to its high affinity to oxidation and high melting temperature (1670 °C) [28]. The processing of titanium foams through casting technique requires equipment capable of maintaining high vacuum and high temperature processing. However, this problem of oxidation and high temperature processing requirement can be avoided by utilising powder metallurgy technique. There are number of methods of processing porous titanium foams based on powder metallurgy route such as conventional pressing and sintering technique [29], gas entrapment technique [3] and space holder method [4, 5, 30, 31]. Among these the space holder method is the most popular one in order to achieve desired amount of porosity, pore shape, size and pore distribution. This technique provides space for tailoring the pore characteristics to achieve the metal foam with desired attributes.

A number of investigations are focussed on finding the suitable implant material that mimics human bones in terms of characteristics features. Niu et al [32] studied the microstructure and mechanical properties of Ti foams with porosity range of 55%–75% and found that the strength of Ti foams were mainly depended upon the density. Tuncer et al [33] reported that apart from the density, pore morphology also influenced the mechanical properties of the Ti foams. Amigo et al [34] evaluated the bending strength of porous Ti and reported that the samples with finer size of space holder possessed higher bending strength. Esen and Bor [35] synthesized Ti6Al4V alloys foams using powder metallurgy technique and studied its microstructure and compressive behaviour. Zhang et al [36] studied the mechanical behaviour and anti-bacterial activity of Ti-Cu sintered alloy having relative density of about 97% of theoretical density of alloy reporting presence of very less porosity. They found using plate–count method of assessing anti-bacterial activity that sintered Ti-Cu alloy showed strong anti-bacterial mechanism due to release of Cu ion. Bolzoni et al [37] observed that the mechanical properties of sintered Ti–3Al–2.5 V alloy got enhanced with the reduction in the residual porosity. Lee et al [38] found that elastic modulus of porous titanium mainly depended upon the porosity and was independent of type and morphology of spacer particles used. Sharma et al [39] investigated the effect of pore morphology and space holder content on the microstructure and mechanical behaviour of Ti foams. They found that fine spacer particles led to generation of uniformly distributed fine pores and concluded that the pore distribution largely controls the characteristics features of Ti foam than the pore size. Singh et al [40] investigated about the effect of spacer size on the microstructure, mechanical and corrosion behaviour of Ti4Al4Co alloy foam. They observed that foam with fine pores showed less porosity and greater relative density resulting into higher yield strength. The corrosion rate was found to be lesser in case of foams with coarser pores than those with fine pores. Singh et al [41, 42] investigated about the effect of various ball milling parameters on the microstructure, mechanical and corrosion behaviour of Ti4Al foam processed through powder metallurgy route. They found that the yield strength and elastic modulus of Ti4Al foam was higher than that of pure Ti foams. They also reported that the foams made of milled powder possessed higher corrosion resistance than those made of unmilled powder.

In present study, efforts are being made to develop potential bio-material possessing the desirable microstructure and mechanical properties. In this research work, an attempt has been made to fabricate Ti-Cu foams by powder metallurgy route. The Cu element which happens to be anti-bacterial in nature is being utilised as alloying element with Ti [36]. In order to achieve the optimized characteristic features, a comparison has been made among the Ti-Cu foams with two different pore size ranges. The effect of pore morphology and Cu content on the microstructure and mechanical behaviour has been investigated to establish a relationship among chemical composition, structure and properties. The results obtained in this study are in preliminary stage, primarily focussing the fabrication, microstructure and its mechanical properties.

2. Experimental procedure

2.1. Raw materials
Titanium powder and Cu powder with 99.9% purity (325 mesh) and with average particle size of 20 ± 5 μm were supplied by Alfa Aesar, US. Acrawax in the form of spherical beads was used as a space holder. The morphology of spherical beads is shown in figures 1(a)–(d). The TGA curve for acrawax beads is as shown in figure 2. It is clear from the curve that the weight percent of acrawax starts declining after 250 °C and the curve for weight percent starts falling abruptly near 350 °C. This indicates the evaporation of acrawax. So, the preheating temperature of green samples was taken to be 350 °C. The space holder particles were taken in form of spherical beads with diameter ranging from 100–1000 μm. Acrawax was divided in two ranges of 100–500 μm and 500–1000 μm with the help of sieve as shown in figures 1(a)–(d). Consequently, for each selected composition there will be samples of two types having pore diameter range between 100–500 μm and 500–1000 μm.
2.2. Selection of composition

Ti powder was used as a base material and Cu powder was used as an alloying element with varying amounts of 3, 5 & 7 wt.%. The composition of sample was decided on the basis of solubility of Cu in Ti and also to obtain less proportion of intermetallic phases. The higher concentration of Cu in Ti causes the formation of much Ti$_2$Cu intermetallic phase which leads to deterioration of mechanical properties of Ti foams [36, 41, 43, 44].

2.3. Foam preparation

The fabrication process of Ti-Cu foams is depicted in the flow sheet as shown in figure 3. The mixture of powder of both the elements was prepared initially by mixing manually for 15 min then further mixing for 1 h in turbula powder mixer in order to achieve uniformity throughout the mixture. Also, in order to ensure uniform mixture, mechanical alloying of the powder was done by planetary ball milling for duration of 1 h with BPR of 5 and ethanol (1 wt %) as process control agent. Acrawax to be used as space holder was divided in two ranges of 100–500 μm and 500–1000 μm was added in the powder mixture by 50% volume and mixed manually for 15–20 min for homogeneous mixture. The obtained mixture was divided into amounts required for preparing number of samples. The powdered samples were then cold compacted at 200 MPa to obtain green pallets in a steel die using a 40 Ton manual motorized hydraulic press supplied by PES Hydraulics (India) Pvt. Ltd. Pallets were made in two shapes (1) Cylindrical (2) Rectangular Bar. Cylindrical pallets were prepared for SEM and
compression testing while the rectangular pallets for flexural testing. The density and porosity of green pallets obtained after cold compaction was examined. The green pallets were then subjected to preheating at temperature of 350 °C with soaking time of 1 h in Electric Tubular Furnace supplied by Mahendra Scientific Inst. Mfg. Co. (India) to remove the acrawax before sintering. Finally, the pallets were sintered in horizontal high temperature vacuum furnace to avoid the tendency of oxidation of metals at temperature of 1100 °C with soaking time of 2 h. The temperature inside the vacuum furnace rises gradually at rate of 12° per minute and reaches upto 1100 °C where it remains constant for one-hour duration for soaking of samples and after that it drops gradually, and samples are cooled down to room temperature.

2.4. Microstructural characterisation
The porosity and density of green and sintered samples were evaluated using Archimedes principle according to ASTM B962-14. The metal foams were then subjected for examination of microstructure by using JEOL 5600 Scanning Electron Microscope. The microstructures were analysed for the pore size, pore wall characteristics and pore distribution.

2.5. Compression test
The plastic collapse stress, plateau stress, elastic modulus and densification strain of metal foams having cylindrical shape was evaluated by performing compression testing with the cross speed of 0.5 mm min\(^{-1}\) on Digital Controlled Universal Testing Machine (50 kN Dynamic) supplied by Bangalore Integrated System Solution Pvt. Ltd, India.
2.6. Flexural test
The flexural stress, flexural strain and flexural stress-strain response pertaining to behaviour of foams subjected to bending stress was determined by three-point bending test using fixture which is set on Digital Controlled Universal Testing Machine (50 kN Dynamics) at cross head speed of 0.5 mm min\(^{-1}\) with 25 mm fixture span.

3. Results and discussion

3.1. Microstructural analysis of Ti-Cu and pure Ti foams
The SEM micrographs of pure Ti and Ti-Cu foams with varying Cu content are shown in figure 4. Foams were divided into two types depending upon the space holder size, one Btype with size ranging 100–500 \(\mu\)m (Below 500) and another Atype size between 500–1000 \(\mu\)m (Above 500). The average size of Ti and Cu particles was 20 ± 5 \(\mu\)m. The microstructures of pure Ti, Ti-3Cu, Ti-5Cu and Ti-7Cu foams with Btype are shown in figures 4(a), (c), (e) and (g) respectively. Similarly, microstructures of pure Ti, Ti-3Cu, Ti-5Cu and Ti-7Cu foams with Atype are shown in figures 4(b), (d), (f) and (h) respectively. The added volume fraction of acrawax (space holder) in both the types was kept to 50%. The sintering was done at 1100 °C for 2 h. During sintering the metals powder get fused and inter particle bonding takes place and acrawax gets evaporated and eventually the cells or macro pores are left behind in Ti matrix. Apart from the macro pores, fine micro pores were also present in the cell walls of the foams. Micro porosities in cell walls were induced due to partial sintering of fine Ti Particles during solid state diffusion. It can be seen from figure 4 that the cells obtained in the foams were nearly circular and mostly interconnected. The interconnected pores (marked as ‘C’) can be differentiated from the isolated pores (marked as ‘I’) in figure 5(a). The figure 5(b) shows the small isolated micropores distributed in the wall of the open interpenetrated macro pores. The little variation in shape of cells as compared to spherical space holder may be attributed to shearing caused during cold compaction. In both the types of foams cells sizes were diverse in nature. In case of Btype cells size range between 100–500 \(\mu\)m equivalent to that of acrawax particles size. In Atype cells were relatively coarser than Btype with size range between 500–1000 \(\mu\)m. The distribution of pores in case of Btype was uniform throughout the surface due to fine size of space holder used, causing ease of mixing with Ti powder. On the other hand, in Atype pores were mainly present nearer to the edges and less uniform over the surface. It is also evident from the micrographs that cell wall thickness varied in the both the types. In Btype foams, cell wall thickness ranged from 50–200 \(\mu\)m whereas in Atype it lies around 150–450 \(\mu\)m.

3.2. Variation of densities and porosities of the foams with respect to pore size and copper content
The table 1 features the values of green, sintered density and porosity percent for both the types of foams with different Cu content. It is clear from the table 1 that values of green densities obtained after cold compaction and sintered densities are lesser than the theoretical values obtained from the following equation (1).

\[
d_{\text{foam}} = \frac{(W_T + W_{Cu} + W_{SH})}{[(W_T/d_{Ti}) + (W_{Cu}/d_{Cu}) + (W_{SH}/d_{SH})]}
\]

(1)

Also, it is clear from table 1 that the density decreases as the size of pores become coarser in case of both green and sintered samples. The coarser size of acrawax has lesser value of density than finer ones. This decrease in density with respect to theoretical values may be attributed to amount of microporosity generated in the respective cases. This is mainly due to lesser shrinkage in coarser pores relative to fine pores. The fine pores show more shrinkage than coarser pores due to sharp curvature which leads to faster densification and lesser porosity. Apart from this, fine pores possess more interconnectivity than coarser leading to more efficient metal deposition during sintering. Also sintered density for the samples is lower than the green density. The reason for which may be the ineffective transfer of load to metal powder during cold compaction due to presence of space holder causing less diffusion among the particles. This causes increase in the number of micropores and decrease in the sintered density. Apart from the pore size another factor responsible for the decrease in densities and increase in porosities is the Cu content. It can be seen from the figures 6(a), (b) that as the Cu content increases from 3% to 7%, the density of foam decreases, while the porosity increases accordingly. The density of Ti-3Cu foam for Btype is 2.17 gm/cc and for Atype is 2.10 gm/cc and for Ti-7Cu foam it decreases to 2.04 gm/cc for Btype and 1.95 gm/cc for Atype. Similarly, the porosity after sintering increase from 49.69 % to 53.69 % for Btype and 53.19% to 57.61 % for Atype for Cu content 3% to & 7% respectively. During the cold compaction and sintering process of Ti-Cu foam the alloying and densification seems to take place through the solid-state diffusion process. The difference in the rate of diffusion of one species into other leads to the kirkendall effect. In this case of Ti-Cu foams, the Cu behaves as fast diffuser as compared to Ti. This is clear from the high diffusion coefficient value for Cu in Ti [45]. This difference in the rates of diffusion will lead to the generation of kirkendall porosity. The higher number of kirkendall pores will be generated on the side of fast diffusing element i.e. Cu rich region. Also, as the Cu content is increased, more amount of Cu will diffuse and will lead to generation of higher number of kirkendall pores. Evidently on increasing the Cu content, a greater number of micropores are generated.
leading to decrease in the density and increase in the porosity of Ti-Cu foams. The highest value of density and lowest value of porosity is achieved in case of B-type Ti-3Cu foam. Many researchers found that the optimum pore size and porosity range for bone implant material is 100–400 μm and 30%–90% respectively \[12, 46, 47\]. It is evident from table 1 that B-type Ti-Cu foam with 3% Cu content show the optimum level of density and porosity.

**Figure 4.** Microstructures of sintered samples of foams (a) Pure Ti foams (below 500 μm) (b) Pure Ti foams (above 500 μm) (c) Ti-Cu 3% (below 500 μm pores) (d) Ti-Cu 5% (above 500 μm pores) (e) Ti-Cu 5% (below 500 μm pores) (f) Ti-Cu 5% (above 500 μm pores) (g) Ti-Cu 7% (below 500 μm pores) (h) Ti-Cu 7% (above 500 μm pores).
Also, the density of Ti-3Cu Btype foam is very much close to the density of human bone (1.8–2.1 g/cc). So, it can be concluded that Ti-3Cu foam produced by powder metallurgy seems to be potential implant material.

### 3.3. XRD analysis

Figure 7 shows XRD graphs of pure Ti powder, Ti-3Cu powder and Ti-7Cu sintered sample. In the XRD pattern of pure Ti powder, the diffraction peaks of Ti is observed. In the pattern of the mixed Ti–3Cu powder, diffraction peaks of Ti and Cu are clearly shown in the figure. In the XRD pattern of the Ti–7Cu sample, besides the peaks of titanium, new peaks can be clearly observed corresponding to Ti$_2$Cu phase, as indicated by a closed circle. Above results display that a new phase Ti$_2$Cu was synthesized after the sintering.

![Figure 7](image7.png)

**Figure 7.** XRD graphs of pure Ti powder, Ti-3Cu powder and Ti-7Cu sintered sample.

| Samples   | Density (gm/cc) | Porosity (%) |
|-----------|-----------------|--------------|
|           | After cold compaction | After sintering |              |              |
| Pure Ti   | 2.70 2.14 2.04 1.84 | 2.10 2.04 1.84 1.65 | 20.84 24.55 | 58.38 62.74 |
| Ti-3Cu    | 2.73 2.39 2.27 2.17 | 2.10 2.04 1.84 1.65 | 12.67 16.83 | 49.69 53.19 |
| Ti-5Cu    | 2.76 2.37 2.24 2.13 | 2.10 2.04 1.84 1.65 | 15.91 18.91 | 53.22 56.10 |
| Ti-7Cu    | 2.78 2.32 2.20 2.04 | 2.00 1.95 1.84 1.65 | 16.50 20.94 | 53.69 57.61 |

![Table 1](image1.png)

**Table 1.** Variation of density and porosity for Btype (Below 500) and Atype (Above 500) Ti-Cu foams with Cu content.

![Figure 6](image6.png)

**Figure 6.** Variation in (a) Density and (b) Porosity of Ti foams with different Cu content.
3.4. Compressive behaviour of Ti-Cu foams

The compressive stress-strain curves obtained from compression test of Ti-Cu foams are shown in figure 8. The figure 8(a) shows the variation of compressive strength of B-type Ti-Cu foams with Cu content whereas in figure 8(b) it is shown for the A-type Ti-Cu foams. The curve showing compressive behaviour of metal foam consists of three regions a) Elastic region b) Plateau region c) Densification region. In the elastic region the variation of compressive stress is almost linear with respect to compressive strain. In this region the elastic deformation of pores takes place and the value of stress reaches to a maximum value known as Plastic collapse stress. In the plateau region, within a limited range of strain the compressive stress oscillates around an average value of stress known as plateau stress. The oscillation of stress takes place in this region due to layer by layer collapsing of the cell walls during compression, hence generating a plateau of stress. In densification region, the foam behaves as solid material due to collapsing of all pores. The stress increases drastically after a strain value known as densification strain.

The variation of plastic collapse stress ($\sigma_{pc}$) with the porosity can be seen from the table 2. It is clear that the $\sigma_{pc}$ decreases as porosity in foams increases. We also know that the porosity in the foams is mainly affected by the pores size and Cu content. The porosity in case of fine pores (B-type) is lesser than that for coarser ones (A-type). As the Cu content in Ti-Cu foams increases from 3 to 7%, the amount of porosity also increases. The combined effects of pore size and Cu content leads to significant increment of porosity which cause the depreciation of $\sigma_{pc}$. The maximum value of plastic collapse stress is reported for B-type Ti-3Cu foam is 147.08 MPa.

The plateau stress ($\sigma_{pl}$) and densification strain ($\varepsilon_d$) for the Ti-Cu foams are determined from the compressive stress-strain curves shown in figure 8. The values of $\sigma_{pl}$ and $\varepsilon_d$ are given in table 2. It is evident from
| Space Holder Size | Samples   | Final Porosity after Sintering (%) | Relative Density | Maximum Collapse Stress (MPa) | Plateau Stress ($\sigma_p$) (MPa) | Densification strain | Elastic Modulus (GPa) | Bending Strength (MPa) |
|-------------------|-----------|-----------------------------------|------------------|-----------------------------|----------------------------------|----------------------|----------------------|----------------------|
| Below 500 Microns | Pure Ti   | 58.38                             | 0.42             | 64.15                       | 36.41                            | 0.61                 | 5.25                 | 37.87                |
|                   | Ti-3Cu    | 49.69                             | 0.50             | 147.08                      | 109.66                           | 0.52                 | 10.70                | 69.13                |
|                   | Ti-5Cu    | 53.22                             | 0.47             | 120.76                      | 71.57                            | 0.59                 | 8.47                 | 66.42                |
|                   | Ti-7Cu    | 53.69                             | 0.46             | 132.08                      | 66.11                            | 0.56                 | 7.06                 | 62.52                |
| Above 500 Microns | Pure Ti   | 62.74                             | 0.37             | 30.90                       | 24.09                            | 0.58                 | 7.54                 | 16.16                |
|                   | Ti-3Cu    | 53.19                             | 0.47             | 126.05                      | 91.52                            | 0.54                 | 10.85                | 62.35                |
|                   | Ti-5Cu    | 56.10                             | 0.44             | 73.95                       | 56.50                            | 0.51                 | 5.16                 | 49.90                |
|                   | Ti-7Cu    | 57.61                             | 0.42             | 68.87                       | 50.57                            | 0.62                 | 3.96                 | 46.12                |
the table 2 that \( \sigma_{pl} \) and \( \epsilon_{d} \) are the functions of relative density of Ti-Cu foams. As the relative density of foams increases, \( \sigma_{pl} \) increases and \( \epsilon_{d} \) decreases. Also, it is clear from the table 2 that value of relative density decreases as the Cu content increases and is higher for Btype Ti-Cu foams than Atype. The relative density of Ti-Cu foams is mainly dependent upon the amount of microporosity and content of Cu present in the foams. It is found that the intermetallic compound Ti_2Cu is formed along with solid solution of Ti-Cu and also the amount of Ti_2Cu intermetallic phase increased as Cu content is increased in the Ti-Cu foams. So, the compressive strength of Ti-Cu foams is dependent on the solid solution strengthening and the intermetallic phase present in the Ti-Cu foams. The intermetallic phase present in the foams is similar to hard reinforcement present in the Ti matrix and behaves as metal matrix composite. The intermetallic phase behaves as brittle material and during compression makes the pore wall brittle from which the crack propagate fastly causing rapid failure of Ti-Cu foams. It is observed that the Ti-Cu foams with lower Cu content show higher values of maximum collapse stress and plateau stress due to high density of the foam, solid solution strengthening and intermetallic phase content. The effect of presence of microporosity is more dominant than the effect of solid solution strengthening. This cause the overall decrement in the value of \( \sigma_{pl} \) and increment in \( \epsilon_{d} \) with increase in Cu content. The variation of \( \sigma_{pl} \) with Cu content for both Btype and Atype Ti-Cu foams is shown in figure 9. It is also clear that the highest value of \( \sigma_{pl} \) is achieved for Btype Ti-3Cu foams is 109.66 MPa which decreases to 66.11 MPa for Ti-7Cu foams. The lowest value of \( \sigma_{pl} \) is 36.41 MPa for pure Ti foam. Similarly, the lower value of \( \epsilon_{d} \) are obtained for Btype Ti-3Cu foams as shown in table 2. The amount of microporosity induced also depend upon the size of pores present in the foams. The inter Ti particle bonding surrounding the coarse pores is comparatively less dense than that for the fine pores. This leads to generation of higher microporosity in Atype Ti-Cu foams as compared to Btype. As a result, the value of \( \sigma_{pl} \) is higher for Btype Ti-Cu foams than Atype Ti-Cu foams.

Elastic modulus is another important parameter of mechanical properties of the Ti-Cu foams. It is also a function of the relative density and pore morphology of the foams. The variation of elastic modulus with respect to relative density can be seen from the table 2. It is known that relative density of Ti-Cu foams is primarily dependent upon the amount of microporosity generated due to addition of Cu content and the coarser nature of pores. It may be noted from the table 2 that as relative density of Ti-Cu foams decreases the elastic modulus of foams also decreases. The elastic modulus value is maximum where the relative density of Ti-Cu foams is maximum that is for Ti-3Cu foams. Also, the elastic modulus for Btype Ti-Cu foams is higher than for the Atype due to finer size of pores and causing less amount of porosity.

3.5. Flexural behaviour of Ti-Cu foams
The bending strength of the Ti-Cu foams was investigated by 3-point bending test. It is another important mechanical property of metal foam to be used for bioimplants. The bending strength of the Ti-Cu foams is mainly affected by the microporosity, surface roughness of pores and non-uniform distribution of pores. The values of bending strength of Ti-Cu foams are given in table 2. It is to be noted that again the highest value of bending strength is for Ti-3Cu foams and lowest for pure Ti foams in both the case of Btype and Attype. With increase in Cu content, bending strength decreases from 69.13 MPa for Ti-3Cu to 62.52 MPa for Ti-7Cu in case of Btype and from 62.35 MPa for Ti-3Cu to 46.12 MPa for Ti-7Cu in case of Attype. The variation of bending strength with Cu content is shown in figure 10, which is found to be linear. It is known that the strength is enhanced with the addition of Cu content by solid solution strengthening. But increase in Cu content also leads to generation of higher amount of microporosity which causes the decrement of strength. Also, the increase in strength due to solid solution strengthening is lower than the decrease in strength due to microporosity. As a
result, the strength increases up to 3 wt.% Cu content and further addition leads to decrement in strength. Another point to be noted from figure 10 is that the bending strength value of Ti-Cu foams is higher for Btype foams than Atype. It may be attributed to more dense and compact distribution of Ti particles in case of Btype foams with fine pores in them and causing less generation of microporosity. On the contrary, Atype Ti-Cu foams have comparatively less dense distribution of Ti particles due to coarser nature of pores causing generation of significant amount of microporosity.

4. Conclusion

The Ti-Cu foams with two different pore size ranges and Cu content (0%, 3%, 5% & 7%) were successfully fabricated by powder metallurgy technique. The following conclusion were made from the investigation of microstructure and mechanical properties of Ti-Cu foams.

1. The distribution of cells was more uniform in case of Ti-Cu foams with finer space holder (Btype) than that of coarser space holder (Atype).
2. The amount of microporosity generated varied with induced pore size and Cu content. The Ti Cu foams with finer pores and lower amount of Cu content retained less microporosity than those with coarser pores and higher Cu content. This leads to decrease in the relative density and increase in overall porosity of Ti-Cu foams with increase in Cu content.
3. The plastic collapse stress and plateau stress decreases while densification strain increases with increase in Cu content. The Ti-cu foams with fine pores possessed high value of plastic collapse stress and plateau stress than with coarser ones. The elastic modulus of Ti-Cu foams was found to increase with its relative density.
4. The bending strength of Ti-Cu foams also decreased with increase in Cu content and was higher for those foams with finer pores.

Acknowledgments

The authors gratefully acknowledge Maulana Azad National Institute of Technology, Bhopal, India and CSIR-AMPRI, Bhopal, India, for providing processing and characterization facility for the research work.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).
Conflict of Interest

None

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