Fabrication and Evaluation of Synthesised Nano SiC Reinforced Titanium Alloy Composites by Powder Metallurgy Route

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Abstract- **In the present study, Titanium alloy (Ti-6Al-4V) with different weight percentage of synthesised nano silicon carbide (SiC) composites was fabricated by powder metallurgy route. The influence of nano SiC addition (0, 5, 10, and 15%) on the properties of titanium alloy was investigated. Phase identification, microstructure and hardness values of the specimens were analysed. A good correlation between phase formation and mechanical parameter was found. The addition of SiC particle enhanced the properties of Ti-alloy composites. The results in this study indicate that formation of new phases plays a major role in the properties of these composites.**

Keywords: Titanium alloy, Powder metallurgy, Hardness, XRD, SEM.

1. INTRODUCTION

Titanium alloy (Ti-6Al-4V) exhibits high strength-density ratio, high temperature stability, and corrosion resistance. So, they are adopted in structural components in airplanes, sports materials and public welfares, and are advanced into vehicle industry [1]. Today, increasing demand for light-weight materials focuses on the series of titanium alloys. The thermo–mechanical properties of titanium alloys can be improved by reinforcing them with ceramics [2]. The nano sized ceramic particles such as SiC reinforced metal matrix composite show excellent mechanical properties [3].Silicon carbide has been widely used in the field of composite materials and semiconducting devices operated in high temperature, high frequency, and high power condition due to their excellent properties. SiC was selected as reinforcement material due to its high strength, high hardness and thermal stability and good resistance to oxidation, corrosion, etc [4].

Powder metallurgy (P/M) has the advantage of better control on the microstructure than the casting methods [5].Powder metallurgy is becoming increasingly important, since it reduces cost by minimizing machining operations and material losses by means of producing highly alloyed materials which can't be successfully produced by conventional methods [6].

In the present investigation, Ti alloy and Ti alloy/ nano SiC composites were fabricated by powder-metallurgy method. The mechanical property, phase formation and microstructure of the specimens were studied. The synthesised nano SiC particles influencing mechanism on the properties of the composite were analysed.

2. EXPERIMENTAL

Commercially available elemental powders such as Titanium (Ti-99% purity) Aluminium (Al) and Vanadium (V) are used as matrix raw materials. Ti-6Al-4V alloy was prepared by mechanical alloying method, using High energy ball mill (Fritch-pulviseriselt-6) [7] with weight percentage of Ti(90%),Al(6%) and V (4%) powders. In this study the reinforced material SiC was synthesised from rice husk ash through simple synthesis method [8]. The size reduction of SiC from micron to nano level (75-100nm) was achieved by high energy planetary (Retsch, PM 100) ball milling. The Atomic Force Microscope (AFM) image of the ball milled SiC nano particles is shown in Fig.1. Average particle size of SiC is 75 nm. The surface of the SiC is irregular and rough. The increased surface roughness supports the higher surface energy of nano SiC.

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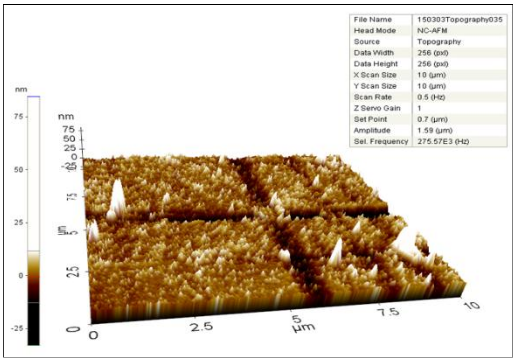

Fig. 1 AFM image of synthesized nano SiC particles.

Experimental samples of Ti alloy and Ti alloy with 5, 10 and 15 weight% of SiC were fabricated through the powder metallurgy route in the following steps. All the powders were milled in a ball mill to obtain homogeneous mixture [9]. The powder mixture was cold pressed into a cylindrical compact at 63 bar [10] by using suitable punch and dies with hydraulic [11] pressing machine assembly.

The compact having maximum density was immediately sintered at 1200°C in the high temperature tubular furnace with argon atmosphere. Choking time of 2 hrs was maintained and followed by cooling to room temperature in the furnace itself [12].Similar procedure was adopted for preparing Ti alloy/nano SiC composites specimens.

After sintering, Ti alloy and Ti alloy / nano SiC composite cylindrical specimens were subjected to secondary processes like hot extrusion (at 850 °C for 30 min)and machining for producing structural shapes and also getting more homogeneous particle distribution with refinement of matrix grains [13].

Phase formation was recorded by XRD using X' PERT PRO PANAlytical diffractometer. Microstructure with elemental composition of the specimen was observed by using JEOL JSM 5610 LV SEM-EDS, and hardness of the specimen was determined by using Vickers hardness testing apparatus (HMV -2T,Schimodzu) with an operating load of 50 g and an indent time of 15s.

3. RESULTS AND DISCUSSION

3.1 Phase identification analysis

Fig.2 shows an X-ray diffraction pattern of sintered Ti-alloy/nano SiC composite specimens with varying SiC content. These composites consist of a αTi phase as a major phase and it is observed for all the spectra nearly at 2θ= 40.16° (101) with d -spacing 2.249 Å. The same phase is also observed at 2θ=35°which belongs to (100) reflection in Ti alloy composite only. The observed values well coincide with the standard JCPDS card no: 89-2762.

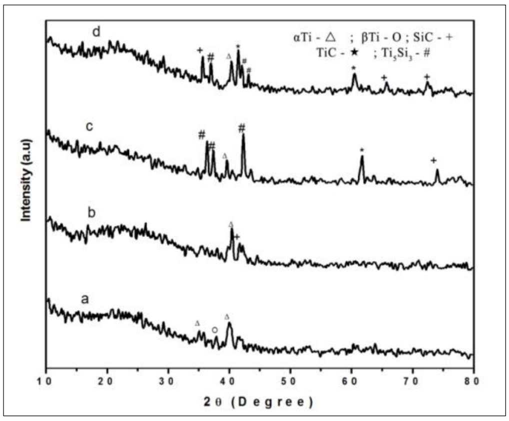

Fig.2 XRD Pattern of a) Ti alloy, b) 5% c) 10% and d) 15% nano SiC reinforced Ti alloy composite specimen

βTi phase is observed at 2θ= 38.45° (110) in Ti alloy specimen (JCPDS card no: 89-3726) [14]. The αTi phase at 2θ= 40.19° (101) is coexistent with a new peak at 2θ=41.48° (104) formed in 5% specimen due to the hexagonal structure of silicon carbide (JCPDS card no: 29-1128). The intensity of αTi phase (peak) significantly decreased in 10 and 15% specimens subsequently some new peaks (Ti_5Si_3 and TiC) with high intensity grew up at 2θ= 36.92°,37.63° and 42.14° ,which belong to (210),(213) and (300) reflections respectively due to Ti_5Si_3phase (JCPDS card no: 08-0041).

The medium intensity of SiC is formed at 2θ=73.39°, (203) (JCPDS card no: 29-1128)and the high intensity of TiC is formed at 2θ=41.43°, (200), and 60.30° (220) (JCPDS card no: 06-0614) in 15% specimen. Formation of new brittle phases (Ti_5Si_3 and TiC) plays a major role in the properties of 10% and 15% composite specimens [2].

3.2. Microstructural analysis

SEM and EDS photographs of Ti alloy and nano SiC reinforced (5, 10, and 15%) Ti alloy composite specimens are presented in Fig. 3(a-d). Microstructure of Ti alloy (Fig. 3a) consists of two phases: the α phase is observed in dark and the β-phase in bright, [15] homogeneously distributed in the matrix. Layer formation with porous nature is seen and the sizes of the pores are less than 1 micrometer and interlocked with grain.

The surface of Ti –alloy with 5% nano SiC was smoothest, and most uniform layer formation was achieved. The uniform distribution of composition can be attributed to good wettability between Ti-alloy and dopant. The well dispersed nano particles can both refine the microstructure of the Ti alloys and act as the reinforcement of the composite effectively [3]. According to Fig.3b, it can be concluded that the 5% nano SiC particle bonded well with the Ti-alloy matrix without the intermediate phase or cracks between them.

Increasing the content of nano SiC (greater than 5%) in the matrix will result in more Ti/SiC interfaces, and hence large number of preferred void formation sites in the 10 and 15% specimens (Fig.3 c&d) indicates weak bonding between the SiC and Ti alloy particles.

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The silica particles are nano size with spherical shape. It is shown that the cracks went through the Ti – SiC matrix interface on the fracture surface[16]. SiC more than 5% can increase the porosity resulting in the decline in strength of the corresponding specimen. This is due to the pore could nucleate at SiC sites and the contact surface area increases, which would result in higher porosity level [17].

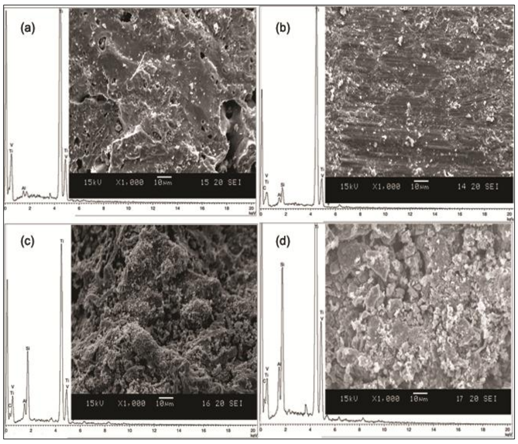

Fig.3 SEM and EDS of a) Ti alloy , b) 5% c) 10% and d) 15% nano SiC reinforced Ti alloy composite specimens

EDS spectra of the specimen are also shown in Fig.3. The peak of Si and C indicate the presence of SiC and the peaks of Ti, Al, and V are attributed to the matrix of Ti-6Al-4V alloy. The % of Si and C values increased with increasing dopant concentration. This confirms the presence of SiC in the doped Ti-alloys specimen.

3.3. Micro-Hardness analysis

The hardness values of Ti alloy and Ti alloy/ nano SiC composite specimens were taken at 3 different places on the surfaces, and the average of these values was considered in this result. At lower load, there is an increase in hardness with increasing load. The presence of such hard surface area of the specimen offers more resistance to plastic deformation which leads to increase in the hardness of the specimen and which is directly related to the forces that exist between atoms in the solid.

Vickers hardness of Ti alloy specimen is (H_V) 380 [18] and the hardness increased significantly for 5 % SiC reinforced Ti alloy specimen to 460, which could be attributed to the presence of harder ceramic particulate in the matrix .The hardness decreased for 10% (369) and 15% (315) specimens, due to greater agglomeration of particles and higher degree of defects and micro porosity present in the specimens. This result well coincides with the SEM observation. This higher hardness value of nano-SiC can provide their inherent properties to the Ti alloy matrix and can act as a hindrance to the dislocation motions which is attributed to the improvement of hardness value. Reduction of porosity was another reason behind the improvement of hardness. The nanometric particulates improve the mechanical properties in the monolithic system because of Orowan strength mechanism [17].

Brittle interfacial reaction products TiC and Ti_3Si_5 are formed (Fig.3 c&d) and the debonding would be expected to occur as a result of processing condition and act as critical flaws, which lower the strength of the 10 and 15% specimens.

4. CONCLUSION

Ti -6Al-4V alloy with 0,5,10 and 15 wt% of synthesised nano SiC reinforced metal matrix composite specimens were fabricated through powder metallurgy route, and the microstructure, phase formation and mechanical property were evaluated. The micro hardness of 5% nano SiC reinforced composites increased significantly when compared to unreinforced Ti alloydue to reduction of porosity. The well dispersed nano particles refine the microstructure and act as reinforcement of the composites. When increasing SiC (greater than 5%) content leads to interfaces were weekend possibly by the pre-existing pores, and brittle interfaced reaction product phases were formed, and this resulted in no beneficial effect on the strength of the 10 and 15% of nano SiC.

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