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CHARACTERIZATION OF P/M PROCESSED Ti/TiC$_P$ COMPOSITES

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ABSTRACT

Titanium and its alloys exhibit excellent combination of physical and mechanical properties, which have made them the material of choice in various aerospace, defense, bio-medical, and corrosion resistant applications. However, high cost of mill products and poor tribological properties are the major drawbacks of titanium based materials. The incorporation of hard ceramic reinforcement has been found to be an excellent method for improving tribo characteristics and augmenting mechanical properties of titanium. The present work focuses on the processing of a Ti/TiC$_p$ composite through P/M route comprising of mixing by ball milling followed by uniaxial compaction and vacuum sintering. Composites with TiC reinforcement loading of 5,10 and 20% have been prepared. The sintered compacts have been characterized by optical microscopy, XRD, corrosion studies and hardness testing. The hardness of the composites showed steady in-crease with increase in reinforcement loading, in spite of the porosity, but the corrosion resistance was observed to be inferior to that of pure titanium samples.

1. INTRODUCTION

Titanium and its alloys are among the key advanced materials in a wide range of applications. The outstanding properties offered by these alloys have made them an indispensable material in a variety of aerospace, bio-medical, marine, automobile, and other applications where corrosion resistance is important. These materials offer some good combination of properties such as low density, high strength, excellent corrosion resistance, good biocompatibility and retention of useful mechanical properties at elevated temperatures. They offer the highest specific strength than any other metallic materials and possess better corrosion resistance than the best of stainless steels [1].
The high specific strength offered by titanium alloys converts to weight savings in aerospace, automobile and other demanding applications. There is an increasing demand for lightweight materials and sustainable manufacturing technologies in transportation sector. The excellent resistance to many highly corrosive environments, particularly oxidizing and chloride containing process streams, have led to wide spread use of titanium in non-aerospace (industrial) applications. Commercially pure titanium is more commonly used than titanium alloys for corrosion resistant applications, especially when high strength is not a requirement [2]. The excellent corrosion resistance, biocompatibility and low modulus of elasticity have made them a material of choice in medical implants. More than 1000 tonnes of titanium devices of every description and function are implanted in patients worldwide every year [3]. The natural selection of titanium for implantation results from the combination of most favourable characteristics such as immunity to corrosion, biocompatibility, high specific strength, low modulus, and density and the capacity for joining with bone and other tissues.

Other potentially useful design characteristics of titanium are its low thermal and electrical conductivity, good ductility, excellent fracture resistance, non-magnetic property, non-toxicity, shape memory properties, and hydrogen affinity (for hydrogen storage). In general, titanium alloys often provide designers the best combination of mechanical properties available among metals [4]. The tribological properties of titanium and its alloys are rather poor compared to most other metals. In sliding, titanium badly deforms and transfers materials to the counterface in unlubricated tribosystems. Under fretting fatigue conditions, strength reduction factors of between 2.6 and 3.6 have been observed for Ti alloys, as a consequence of associated material loss. The abrasion resistance of Ti alloys is also poor compared to most other materials. From theoretical calculations, metals with low theoretical tensile and shear strengths exhibit higher values of coefficient of friction than higher strength materials within the class of hexagonal close packed (HCP) structure. The great affinity of Ti for oxygen results in the formation of oxide surface layer, which too is transferred to and adheres to non-metallic materials, such as polymers, resulting in severe adhesive wear. The poor surface properties restrict the use of titanium to non-tribological applications [5]. Dennis.P.Townstead (1991) had reported that titanium would be an excellent gear material if methods were devised to improve its sliding and wear properties. Budinski (1991) found that for dry sand/ rubber wheel abrasion tests, pure titanium and Ti-64 alloy wore at a rate 15 times higher than D2 tool steel. His studies have recommended avoiding pure titanium in unlubricated tribosystems as it badly deforms and wear out at a rapid rate. To realize the full benefit of Ti alloys in non-aerospace and wear resistant applications, there is a need for the development of low cost production methodologies and vast improvements in tribological properties.

For applications where wear resistance is required, titanium alloys can be used as a structural material only after a specific surface treatment aimed at improving their tribological behavior. A variety of surface modification techniques such as physical vapor deposition, thermochemical conversion treatments, plating and the application of solid lubricants have been utilized [7]. Composite concept has been pursued in the recent periods to improve the tribological characteristics and augmenting the mechanical properties of titanium and its alloys.

The addition of hard ceramic particles to produce a titanium matrix composite has been found to be an effective method for enhancing wear resistance and augmenting the mechanical properties [8]. The particles strengthen the Ti matrix, which increases the hardness relative to the unreinforced matrix. Powder metallurgy processing of the MMC offers advantages such as simplicity associated with the incorporation of the particulate reinforcement phase into the matrix through the mixing of powders, better properties due to better control in interfacial reactions and near-net shape capability. Titanium being a highly reactive metal, its processing through cast melt route is very difficult. P/M has enjoyed reasonably good position among metal working technologies and improved its position against other near-net shape technologies such as investment casting, isothermal forging etc. Further, press and sinter P/M processing has been successfully utilized as a cost-effective fabrication method for producing near-net shape components (primarily of ferrous alloys), in the automotive industry.

The present work focuses on the processing and characterization of TiC particulate reinforced pure titanium composite processed through uniaxial compaction and vacuum sintering. The study examines the influence of reinforcement addition on the microstructural development, hardness and corrosion resistance of the composite.

2.EXPERIMENTAL PROCEDURE

Composite powders with 5,10 and 20 vol.% reinforcement loading were prepared by mixing of the titanium and TiC powders in a planetary ball mill. The average particle size of the constituent powders as found by laser particle size analysis was 111 and 46 microns respectively. The ball mill mixed composite powder was further processed by P/M processing comprising of uniaxial compaction and vacuum sintering. The sintered density of the compacts was determined by Archimedes Principle. The sintered compacts were further characterized by optical microscopy, XRD, hardness testing and corrosion testing.

3.RESULTS AND DISCUSSION

The results of the particle size analysis of pure titanium and TiC powders are presented in Fig.1 and Fig.2 as cumulative % Vs Particle size in microns. The average particle sizes are found to be 111µm for titanium and 46 µm for TiC powers.

3.1 COMPRESSIBILITY STUDIES

Compressibility studies were carried out to assess the compaction behavior of the powders. The reference density and apparent density details of the compacted powders are shown in Table.1. Plots of green density Vs compaction pressure for pure titanium and Ti/TiCp composite powders are shown in Fig.3. The optimum compaction pressure in uniaxial compaction for the pure Ti and Ti/TiCp composite powders were optimized at 700 MPa, the load beyond which the green density of compacts showed no appreciable increment. The green density initially showed increase with increase in compaction pressure and eventually became almost constant.

It is impossible to achieve full density in cold compaction as the hydrostatic stresses around pores prevent the complete closure of pores. The compressibility shows gradual decrease with increase in reinforcement loading. The presence of hard ceramic particles impedes the densification of green compacts. At higher pressures the densification mechanisms like plastic deformation and interparticle locking gets inhibited by the presence of ceramic reinforcement particles.

3.2 SINTERING STUDIES AND CHARACTERIZATION OF COMPACTS

Sintering of the compacts was carried out at 1200^{o}C for 1-4 hours, and at 1300^{o} and 1400^{o}C for one hour each. The variation of sintered density with sintering temperature is represented in the graph in Fig.4. The sintered densities of the compacts show an increase with increase in sintering temperature. The variation of sintered density with sintering time of 1-4 hours is about 2%. Thus, temperature is observed to be the predominant factor influencing densification.

One of the major problems in production of MMCs by P/M route is the agglomeration of reinforcement particles due to size difference between powders of matrix and reinforcement. The unetched optical micrographs of the sintered compacts are shown in Fig.5. The TiC reinforcement particles are well dispersed in the titanium matrix for Ti/TiC_p composites.

3.2.1 MICROSTRUCTURAL STUDIES

Fig.6 shows the etched micrographs of pure titanium samples at different sintering temperatures. Pure titanium showed extensive grain growth with increasing sintering temperature, as is evident from the etched micrographs of samples sintered at 1200^{o}, 1300^{o} and 1400^{o} C. For the Ti/TiC composites, the grains adjacent to the TiC particulates appeared to be finer as is evident from the micrograph shown in Fig.7. This explains the better sintering response of composite samples with higher reinforcement loading compared to pure titanium. Similar results have been reported in literature [8]. The finer grains aid sintering, especially in the intermediate and latter stages of sintering, where grain boundary diffusion is the dominant mechanism of mass transfer.

3.2.2 PHASE ANALYSIS

Fig.8 and Fig.9 show the XRD patterns of pure Ti and Ti/5 TiC_p composites respectively. None of the patterns showed any titanium oxide peaks

3.2.3 HARDNESS STUDIES

The results of Vickers Hardness measurements for Ti/TiC composites are represented in the graphs in Fig.10. The Ti/TiC composites showed steady increase in hardness with increasing reinforcement loading. The hard TiC particles generally strengthen titanium matrix and thereby increase the hardness of the MMC.

3.2.4 CORROSION STUDIES

The results of potentiodynamic corrosion tests on pure titanium and Ti/TiCp composites are shown in Fig.11 and 12. The polarization curves show a clear shift towards the right indicative of a rise in corrosion current and thereby indicate reduction in corrosion resistance of the composites compared to pure titanium. The variation of corrosion current with increase in reinforcement vol. fraction of the composites is represented in Fig.11. The inferior corrosion resistance of composite samples can be attributed to the formation of non-stochiometric TiC around the TiC particulates, which had been reported by researchers [10]. Besides, the density of composite samples is in general lower than that of pure titanium samples, which expose more surface area to the corrosive media.

4.CONCLUSIONS

1. Ti/TiCp composite powders with 0, 5, 10, and 20 vol.% TiC reinforcement have been prepared by mixing titanium and TiC powders in a planetary ball mill.
2. The distribution of reinforcement in the titanium matrix is found to be uniform for the composites.
3. The grain size of pure titanium compacts showed an increase with increase in sintering temperature.
4. The Ti/TiCp composites showed higher hardness compared to pure titanium, and hardness showed steady increase in reinforcement loading.
5. The corrosion resistance of Ti/TiCp composites is found to be inferior compared to pure titanium.

5.REFERENCES

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TABLES

Table 1: Composition, Reference density and Apparent density of the powders.

Composition	Reference Density (g/cc)	Apparent density (g/cc)
Pure Ti	4.51	1.54
Ti/5 TiCp	4.52	1.46
Ti/10 TiCp	4.54	1.46
Ti/20 TiCp	4.59	1.45

FIGURES

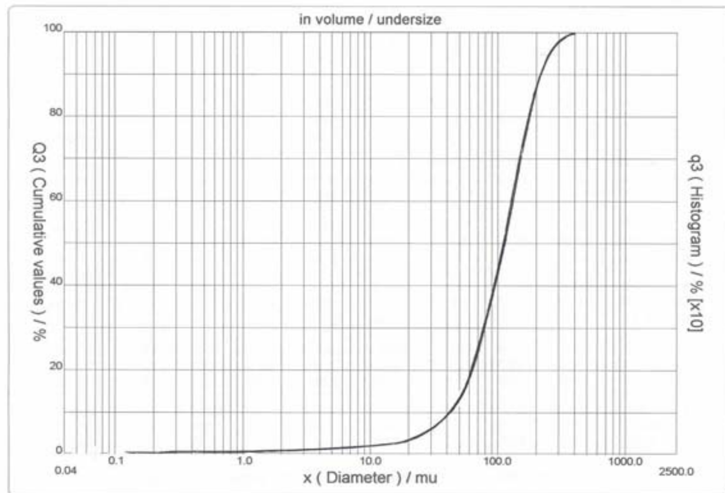

Fig.1 Graph showing the cumulative % Vs Particle size in microns for pure titanium powder

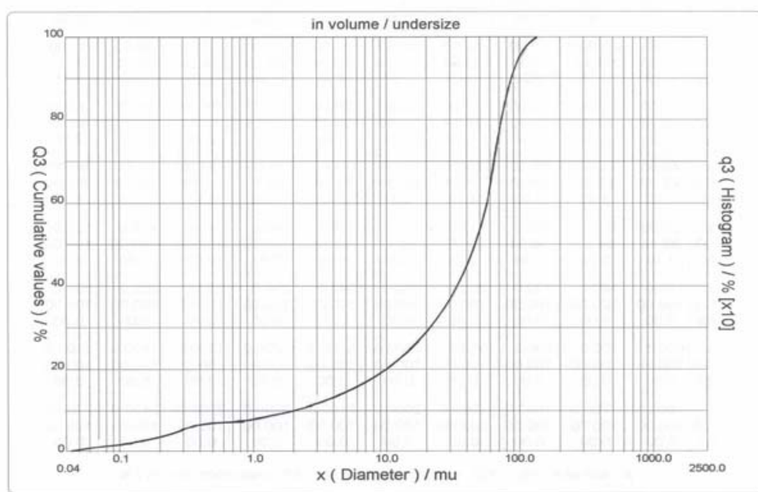

Fig.2 Graph showing the cumulative % Vs Particle size in microns for TiC.

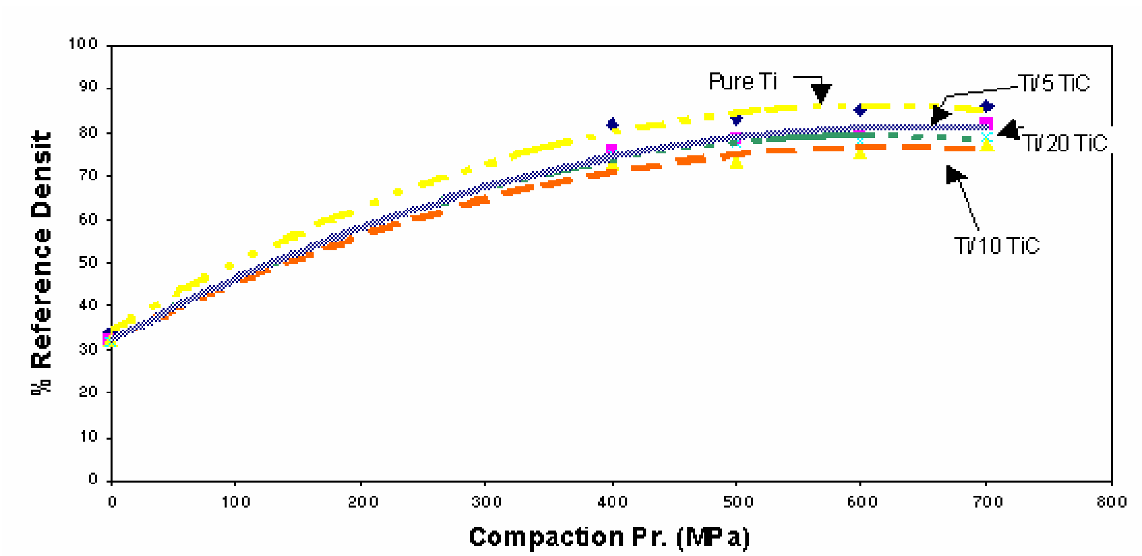

Fig. 3. Graph showing variation of green density with compaction pressure

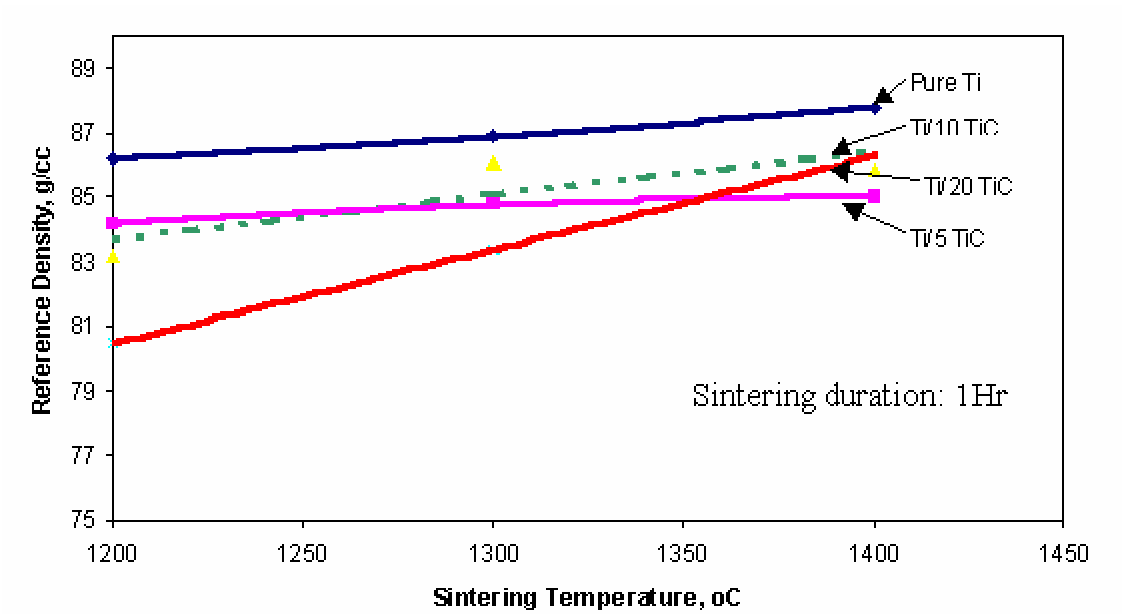

Fig.4 Graph showing the variation of sintered density with sintering temperature.

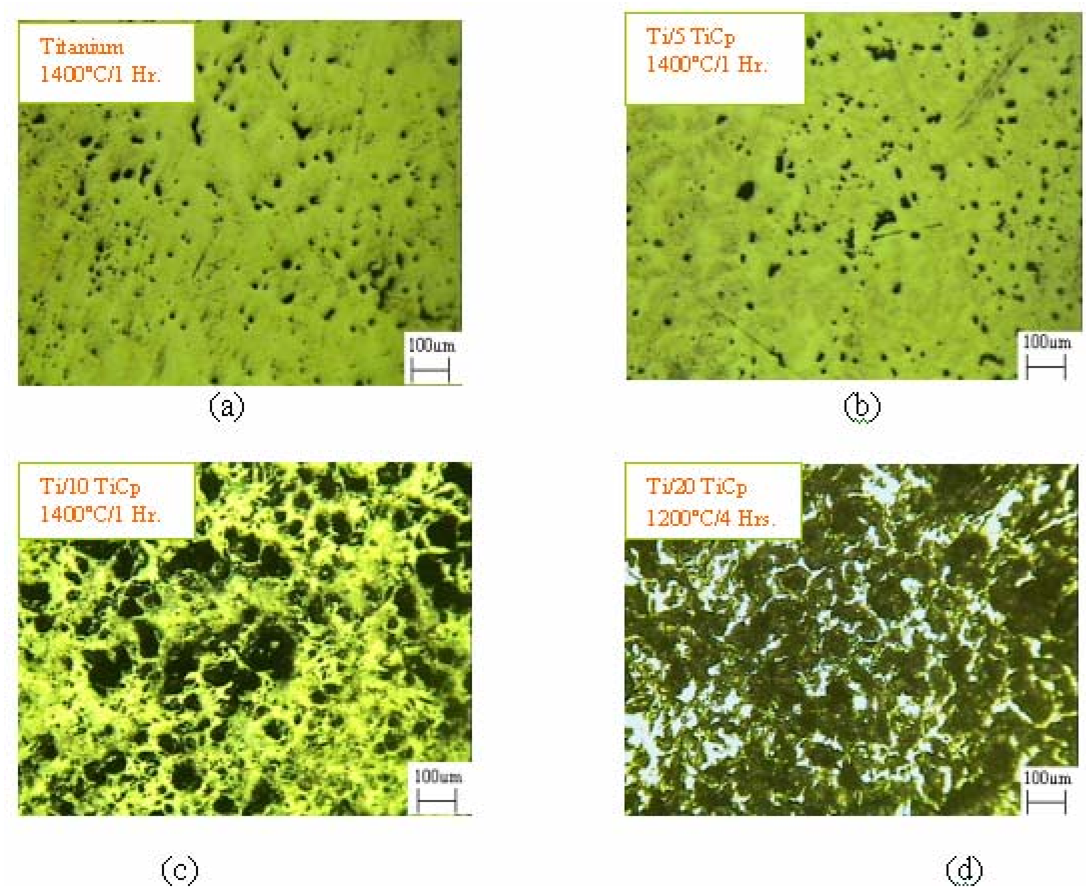

Fig.5 Unetched micrographs of pure titanium and Ti/TiC composites.

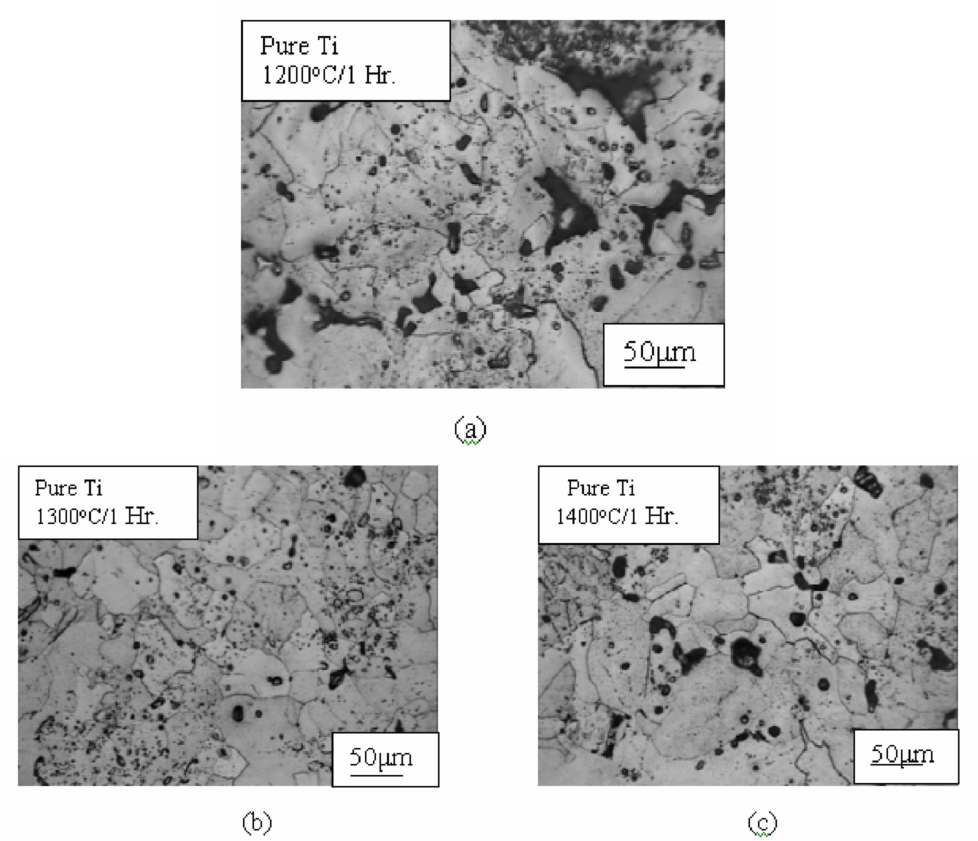

Fig.6 Etched micrographs of pure titanium samples sintered at: (a) 1400^{o}C/1 Hr., (b) 1300^{o}C/1 Hr., and (c) 1200^{o}C/1 Hr.

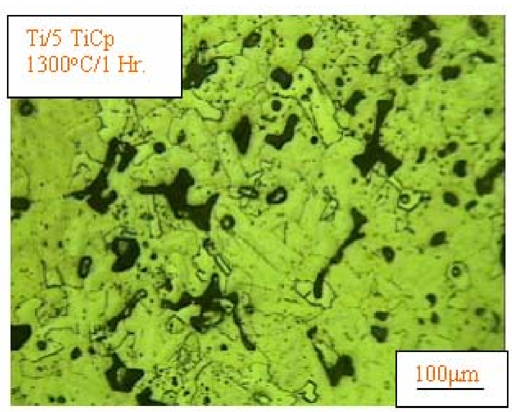

Fig.7 Etched micrograph of Ti/5 TiC composite.

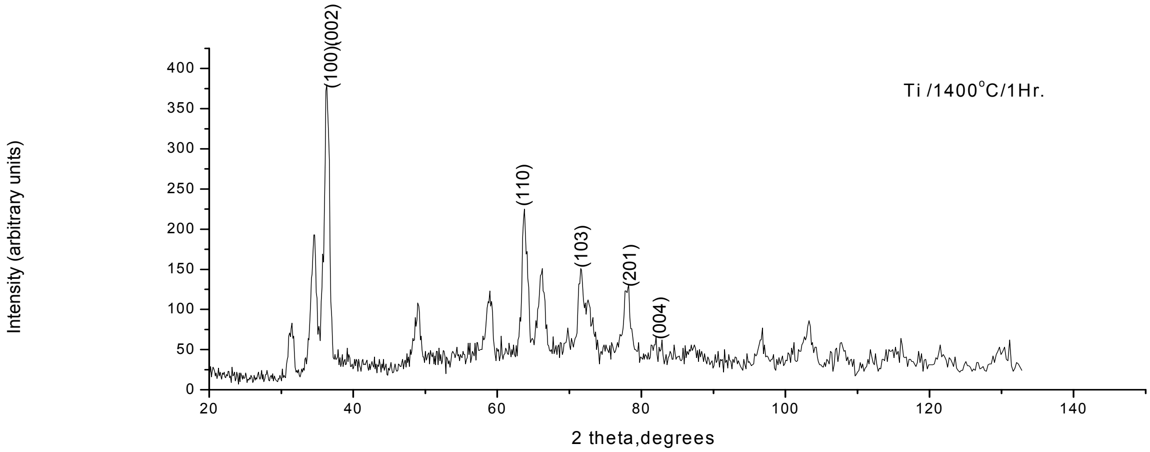

Fig.8 XRD pattern of pure titanium sintered at 1400°C /1 Hr.

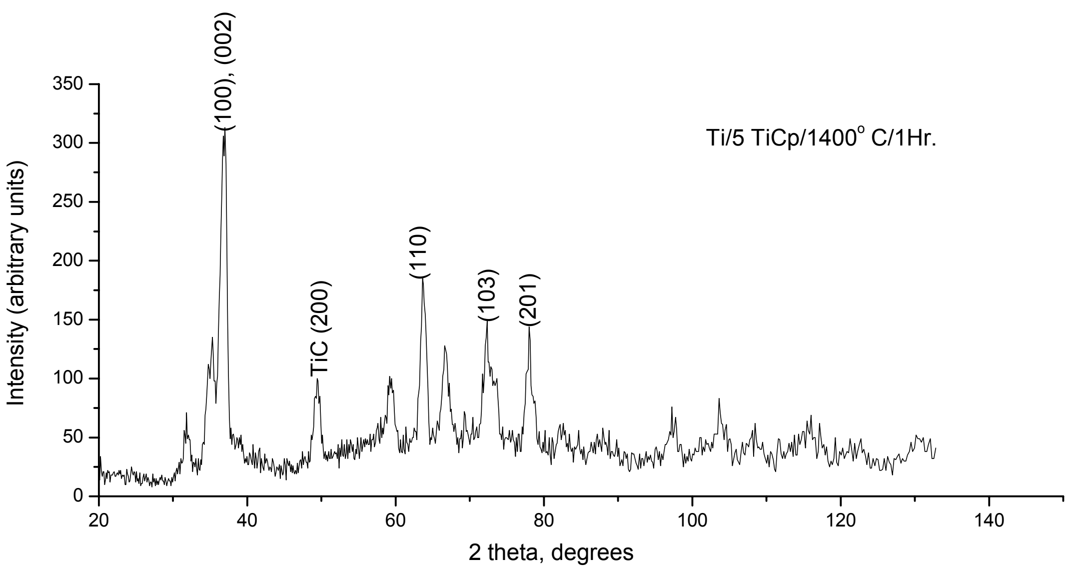

Fig.9 XRD pattern of Ti/5 TiC_p composite sintered at 1400°C/1 hour.

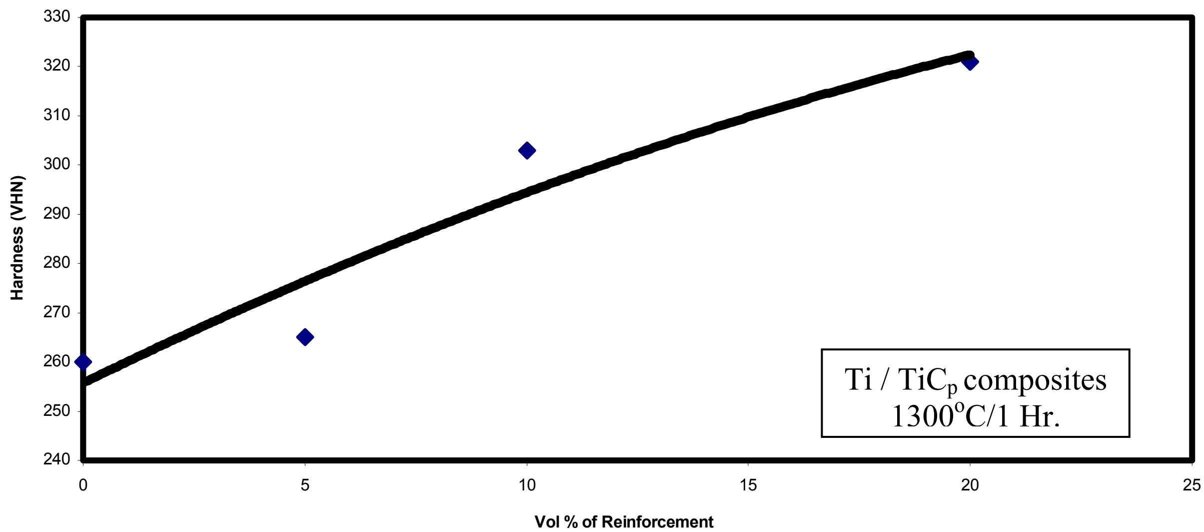

Fig.10 Variation of hardness with reinforcement loading for Ti/TiC_p composites.

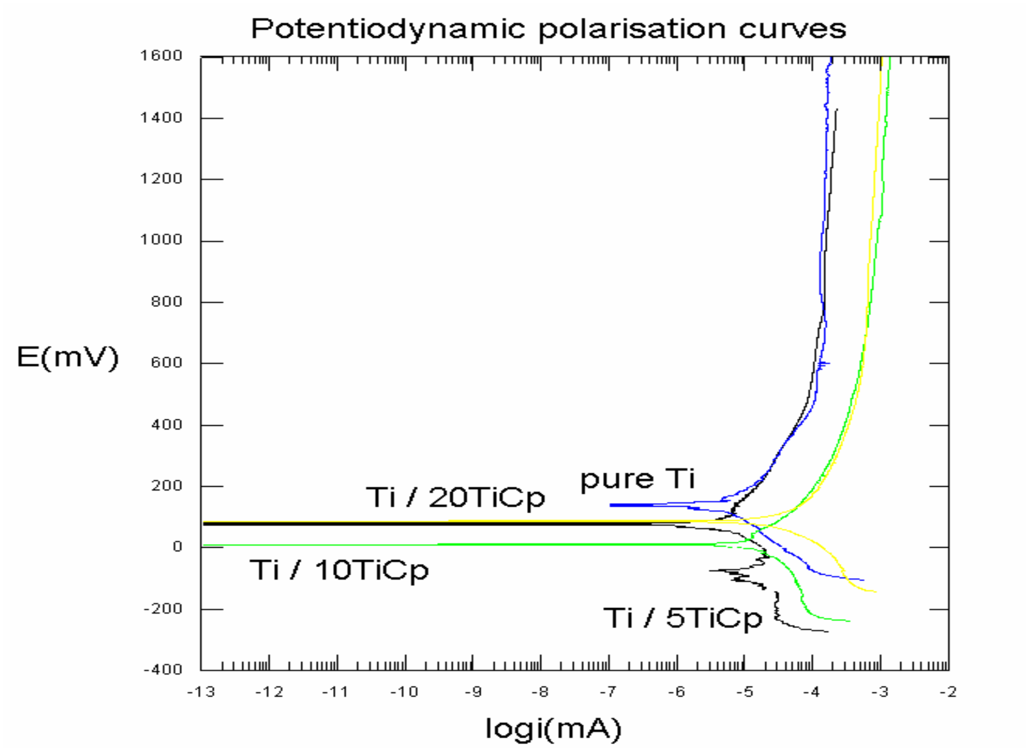

Fig. 11 Potentiodynamic polarization curves for pure titanium and Ti/TiCp composites all sintered for 1 Hr).

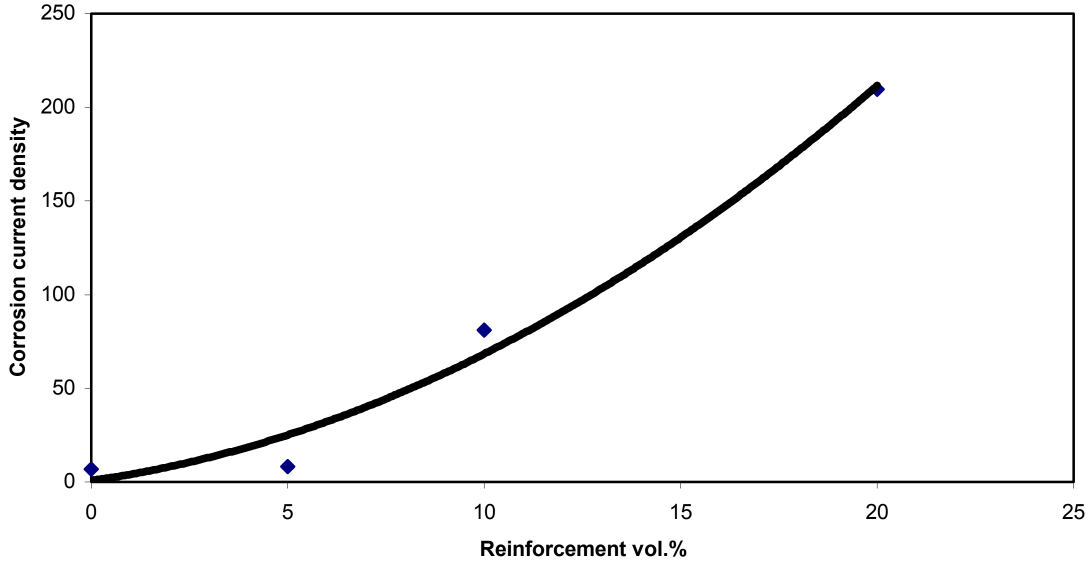

Fig. 12 Graph showing the variation of Corrosion current (i_{corr}) with Reinforcement vol.% for Ti/TiCp composites.