" Tribological Properties and the Effect of Graphene Nanoplatelets on Ti-64 based Hybrid Composites for Aerospace applications "

Thesis

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Production Engineering

By

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CERTIFICATE

This is to certify that the Minor Project Report entitled***, "An Effect of Graphene Nanoplatelets on Tribological Properties of Ti-64 based hybrid composites for aerospace applications"*** submitted by **Mr. Abhishek Thakur** to Thapar Institute of Engineering & Technology, Patiala, India, is a record of bonafide Project work carried out by him under our supervision and guidance and is worthy of consideration for the award of the degree of Master of Technology in Mechanical Engineering with Specialization in "**Production Engineering**" of the Institute.

This work, in my opinion, has met the requirements for the award of the degree of Masters of Technology in accordance with the Institute's regulations.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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Finally, but most importantly, I am grateful to Almighty, my Lord, for providing me with the determination and strength to get this far.

Date: 29/July/ 2022 **Abhishek Thakur**

Place: Patiala (ME PRODUCTION)

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DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no previously published or written material by another person, nor material that has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text.

(ABHISHEK THAKUR)

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ABSTRACT

In this report, the powder metallurgy-derived composite materials were investigated. The current research looked at the tribological patterns of Ti-64 which is Titanium 6-Aluminium 4-Vanadium composites for tribological properties was examined. For this purpose, Ti64 composites for three samples had been created using procedure of Spark Plasma Sintering (SPS). Using the essential and crucial method known as Spark Park plasma sintering (SPS), powder particles can be rapidly aggregated by applying current and pressure simultaneously. As in present research, SPS processed 100 percent industrially pure titanium was produced through a three-step sintering procedure densification. The procedure had been a three-step one chosen after comparing it to either cumulative or one step sintering cycles. Nano-indentation and high frequency techniques were used to determine the elastic modulus, as well as the toughness and uniaxial compressibility at ambient temperature.

Mechanical characteristics like micro-hardness and Vickers hardness were also measured at room temperature. Microhardness measurements from Vickers's hardness test for the three materials were slight differences in their hardness values. Microhardness measurements show that the Ti–6Al–4V alloy of sample T1 is harder than the remaining other two samples because of the element addition of Fe for 0.85% of mass percentage. Tribometers were used to perform sliding wear tests on requisite samples of Ti-64. The a particular wear rate rises as the normally applied load rises, but after a certain time, say after 2000 m sliding distance, wear becomes stagnant. From 30N to 50N, sample T3 shows an 88 per cent improvement in wear rate. The greatest weight loss was discovered to occur at higher load values. Furthermore, the wear rate decreases as the normal load decreases.

Surface morphology was also examined to get the requisite wear track analysis right after tribology via Scanning Electron Microscope (SEM) technique. SEM micrograph images show that most significant abrasive wear, ploughing, and plastic deformation dominant wear mechanisms in a Ti-64 mixed reinforcement composite sample at loads of 10N, 30N, and 50N and a sliding velocity of 1m/s. At a load of 10N and a sliding velocity of 1 m/s, Delamination, oxygenation, and abrasive wear were named as the dominant wear mechanisms. The at loads of, the composite materials surface exhibited delamination and plastic deformation wear 10 N and 30 N with sliding velocities of 1 m/s respectively. X-ray diffraction was also utilised check the crystallographic behaviour of the requisite samples of Ti-64. Properly refined peaks can be seen from XRD data in context using the use of X'Pert high score plus software, allowing the required miller indices for identification of lattice size and lattice strain values were calculated.

Keywords: Tribological behaviour, Spark Plasma Sintering, Sliding Wear, Mechanical properties, Microhardness, Ti-6Al-4V

CHAPTER 1

INTRODUCTION

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INTRODUCTION

1.1 Objectives and Purpose

Grade 5 Titanium has one of the foremost prevalent combinations within that adds to nearly 50 percent of the titanium utilized within the globe. Generally alluded toward by way of Ti-6Al-4V or (Ti-64), that description is generally refers to the chemical makeup of nearly titanium 90 percent,6% aluminum, Vanadium, 4 percent , maximum concentrations of 0.25 percent iron and 0.2% oxygen. It cope up with great strength, less elasticity modulus, more corrosion prevention, great weld efficiency and that's able to be heated. Elements like vanadium and aluminum are added increments the brittleness of the substance within the metal medium, with systematic approach of mechanical and physical characteristics [1].

- Strong Tensile power —The strength of Titanium 6Al-4V is comparable in comparison to stainless steel, necessitating powerful cutting forces.

- Low-slung or insufficient thermal conductivity—High temperature does not easily pass hooked on the chip, instead of flowing the cutting instrument, causing the latest to become extremely burning throughout the machining process.

- The titanium has a high modulus of elasticity, making it particularly "spongy." For a given force, it will deflect more than steel, which causes more vibration, chatter, and poor chip formation.

- Shear mechanism—To cut titanium and stay away from tearing and smearing, that will swiftly cause tool failure, a sharp cutting edge is required.

At vast pace, the pure titanium and titanium alloys for use in industry are commonly utilised in aircraft as a material that is strong and lightweight, with a density that is 60 percent aggregate that of steel, and excellent corrosion prevention. In recent research works, the required part of application ratio toward the number of engines to that of airframe components has been increasing to increase aero plane fuel efficiency consumption. Similarly, the demand for titanium is increasing. In terms of corrosiveness, it has great compatibility with CFRP as well as concerns with thermal expansion coefficients. The titanium content A350XWB, a low-fuel-consumption aero plane, uses this technology. Airbus S.A.S., which uses a lot of CFRP, has gained in popularity[2]. More than twice as much as is utilized in traditional aircraft. The main types of commercially available titanium are pure titanium and titanium alloys like Ti-6Al-4V which is used for aircraft engine components. Due to the minimal fuel consumption of aircraft, the possibility of drastic growth in demand conquered. On the other hand, a wide range of degrees and a high level of quality management is required to enter into the aircraft business necessitates quality control. Between 2007 and 2010, Titanium industrial demand is predicted to outpace a vital role in the GDP expansion, owing primarily to the widespread utilisation of titanium in the aerospace sectors for the entire recent years, for example, the expansion of modern titanium consumers, like the oil natural gas industry, large automobiles and medical gear are all examples of installations.

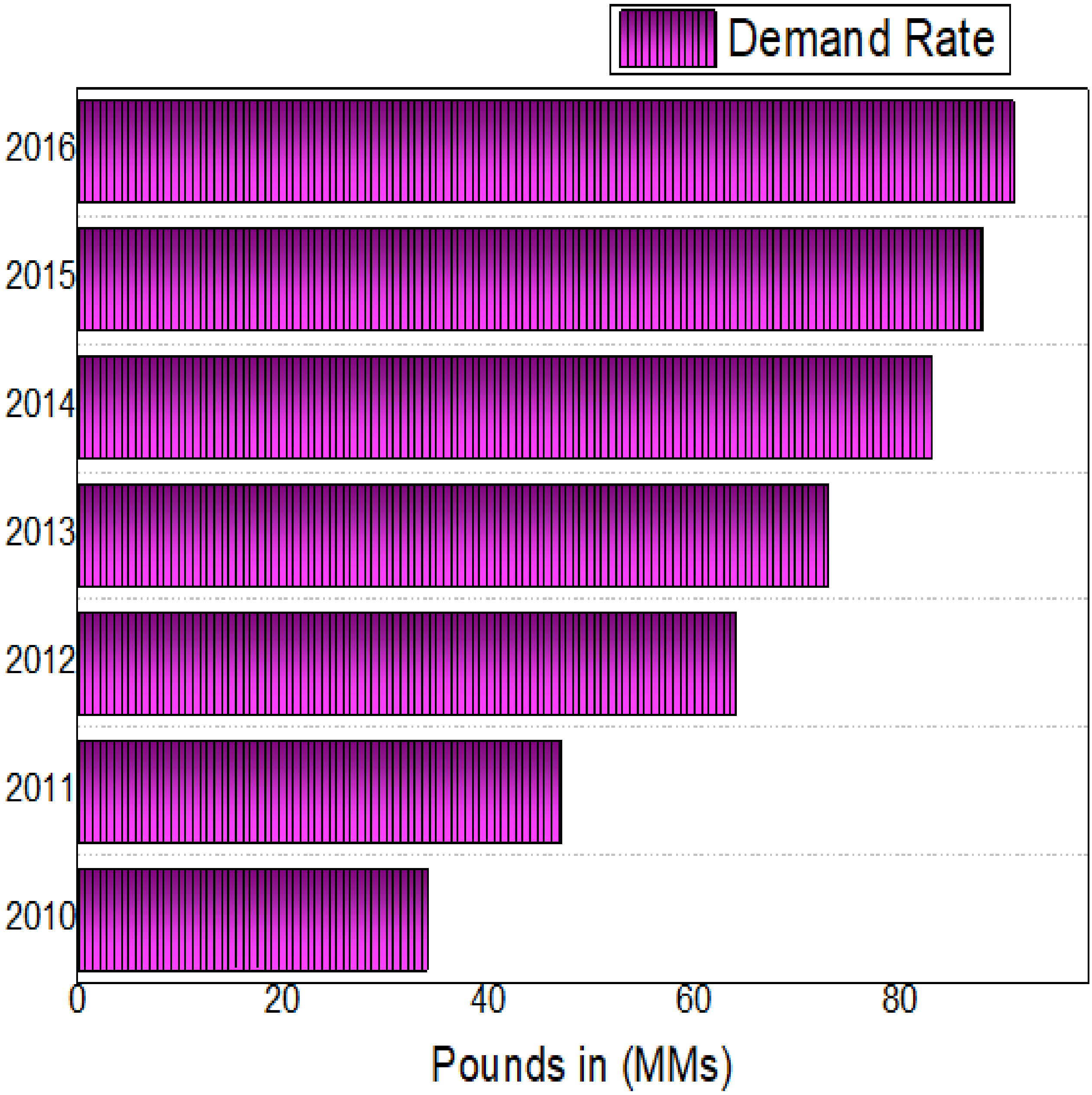

Figure 1.1 *Titanium demand data from research journal [1]*

1.2 Importance of Research

National

Hussein et al. [3] reviewed the way metallic-based biomaterials wear. High mechanical toughness with the best biocompatibility, and corrosion prevention, portable and a comparatively low elasticity modulus are fundamental properties of Titanium alloy that making them an appealing candidate for biomedical uses.

Lepika and Dahlke [4] reviewed various surface modification techniques for creating triboadaptive Ti64 surfaces for biomedical applications.

Song et al. [5] examined the influence the process criteria for Ti64 microstructure, densification, surface abrasion, and microhardness.

Haseeb et al.[6] investigated wear from dry sliding properties against hardened steel of Ti64 and the various in combination alloys. They concluded that Ti64 had requisite lower wear resistance as a result a shielding oxide layer.

Dr. S Ranganatha and Nadeem Pasha K investigated the 5th graders' sloping responses Using a pin-on-disc test rig, test titanium alloy. The outcomes showed friction coefficient was affected by the sliding speed [7].

International

According to Zherebtsov et al. [8], the realisticway of applying hysdrostatic from all directions and multiaxial forging tailed by cold rolling process generally for Ti-6Al-4V alloy with very high tensile behaviour of about 1000 to 1200 MPa, whereas forging combined with heat treatment results in Ti-6Al-4V alloy with moderate strengths of about 1250 MPa and 1020 MPa, respectively.

Poondla and other researchers [9] measured reequisite microhardness (Vickers scale) then microhardness for the Ti64. The authors found minimal difference across a cross-section of the samples in microhardness and attributed this behaviour which changes the microstructure. Various authors attribute the lower macrohardness value that considering the microhardness of the Ti6Al4V and the physical occurrence for processing-related artefacts.

Molineri et al. [10] reported that deprived tribological behaviour of Ti alloy remain caused by two initiate factors: (i) low resistance to plastic shearing and (ii) the oxide layer's ineffective protection at more temperatures. Molinari investigated the tribo-characteristics of Ti64 which the sliding occurs against the identical material's reverse at different speeds as that of applied loads. Comparison in wear rates as a result of changing speed and load circumstances.

C Veiga et al. [11] reviewed the characteristics and uses of titanium composites. It was noted that the importance of titanium composites in the aircraft industry cannot be overstated. They also emphasised the significance of Titanium alloy wear performance by using pin-on-disc apparatus.

Danilo Fontes et al. carried out trials with a pin-on-disk responding tribology behaviour that could add a corrosion prevention measure. Also discovered a significant amount of material was lost due to variation in the loads and speeds. [12]

Sdobnyakov, Nickolay Yu. and others simulated the phase transfer mechanism in titanium nano alloy utilising cooling rate as a parameter. The imitation aided in determining the precise characteristics of structural development [13].

Grzesik, Wit, and others used a pin-on-disc test apparatus to evaluate the tribological behaviour of a dual-phased titanium alloy tribo system and carbide inserts coated with Ti-Al-N. They discovered severe abrasive wear as well as adhesive wear [14].

S Anandan et al. carried out research on the using a pin on disc test rig, determine the wear behaviour of titanium alloys. Titanium exhibited superior wearability style, according to the findings. [15]

2.0 OBJECTIVES

(1) Fabrication of Titanium alloy that is Ti-64 (Grade 5) via Spark plasma sintering process.

(2) Study and understanding of the requisite samples of Ti-64 via EDS that is energy dispersive X-ray spectroscopy in order toward getting the chemical behaviour or elemental configuration of the material.

(3) In order to ascertain the underlined crystal structure of a substance X-ray diffraction incorporated with the High score plus software to check the crystallinity of the material.

(4) Vickers hardness evaluation is performed to determine the material's hardness under specified conditions.

(5) Study of the tribological characteristics of the material by utilising a dry sliding wear test by using pin-on-disc technology.

(6) Examination of surface morphology of the sample to be checked via Scanning electron microscopy (SEM) images.

CHAPTER 2

Background

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Literature Review

CHAPTER 2

Background and Literature Review

2.1 Titanium (Ti)

Ti is the fourth most abundant element, ranking ninth overall. Metallic structures, trailing only aluminium, iron, and magnesium. It occurs naturally within mineral sands as ilmenite or rutile As a result, Titanium and its alloys form a corrosion-resistant and biocompatible passive oxide film. The metal is rare in large quantities or in pure form, and it is difficult to purify the oxide, making pure Ti metal expensive.

2.1.1 Physical Properties

Ti is the lightest of the heavy metals. It is twice as dense as Al but has half the specific weight of Fe, Ni, or Cu. It has one-tenth the thermal conductivity of Al and one-third the thermal expansion of Al (half that of steel). Table 2.1 [16] demonstrates a few of pure titanium characteristics.

Table 2.1 *At 25 ºC , selected physical properties of -Ti with greater than 99.9% purity [16].*

Thermal expansion co-efficient [10^6 k^{-1}]	8.26
Thermal Conductivity [W/mK]	14.09
Elastic Modulus [GPa]	115
Poisson’s ratio	0.3
Physical properties of -Ti, > 99.9% pure at 25ºC	

2.1.2 Crystal Structures

Ti has allotropic properties that are related to its atomic structure and bonding. It exists in a closed hexagonal container at room temperature named as the α -phase. When the temperature exceeds 880 °C, phase transformation occurs, and Ti element exists in the structure with a body centre cubic (bcc), also named as the β-phase. As a result, this is also called the transus temperature (β_T). It persists the β-phase until its melting point (T_M) of 1650 °C, also known as the liquidus temperature [17].

Figures 2.1 (a) and (b) depict hcp and bcc Ti crystal structures with lattice parameters, respectively. The bcc atomic cell has two in atoms and a Factor of atomic packing of 0.68. The unit cell hcp, which has a atomic packing factor of 0.74 and 6 atoms., is more densely packed [18].

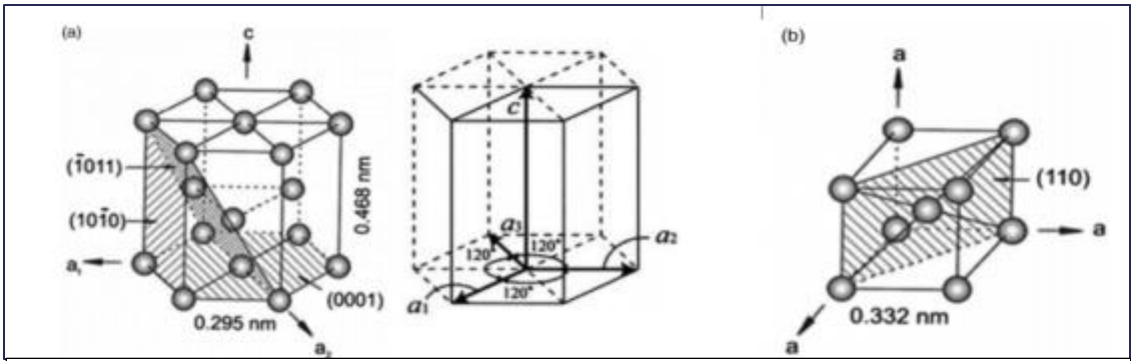


Figure2.1 *The crystal structures and lattice parameters of (a) α and (b) β-phases of Ti[16,19]*

2.2 Ti Alloys

Conventional Ti alloys retain their high specific strength up to 500°C, with only their oxidation behaviour limiting them. Ti-aluminide (Ti-Al) overcomes this to some extent and competes well utilising Ni at high-temperature. As a result, Al is still an important Ti-alloy stabilising element. Ti and Ti based composites are corrosion-resistant and have a high specific strength., in addition to it the textures due to their light weight, transformation microstructure, passive oxide film, allotropy, and high T. As a result, they found early success in the aerospace, chemical, marine, bio-medical, architecture, and power industries. However, Ti and Ti alloys are also associated with machining difficulties [16]. However, AM technology now avoids this.

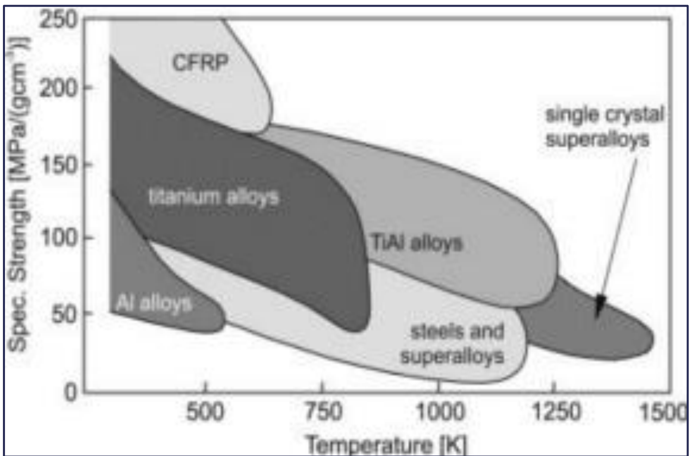


Figure2.2 *Ti-alloy specific strength vs. temperature in comparison to selected materials [16].*

2.2.1 Alloying elements

Ti can be alloyed with substances known as stabilisers. Such elements have an effect on the material's properties (e.g., by changing the T) and are frequently classified based on their effect on the T. When the phase field is increased, the stabilisers raise the -phase field temperatures and form two phases (α+β). Al, Ti is essential component of alloys. Mo, V, Ta are more vital and soluble in Ti, whereas eutectic phase can form metal-metal compounds. Tin and Zirconium are two examples of neutral elements. As shown in Figure 2.3, the elements with little charge effect on the T. With a few hundred parts-per-million non-metal elements (impurities) [16,17,20].

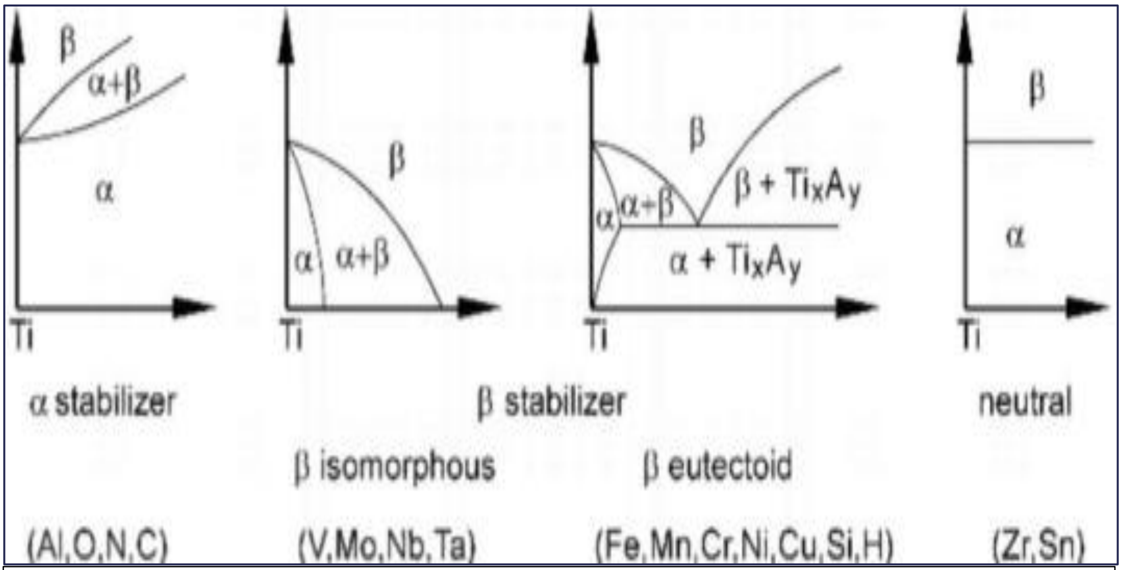


Figure 2.3 *Phase diagrams, showing the effects of alloying elements on Titanium [16]*

2.2.2 Ti- categorization of alloys

Alloys, near-alloys, and metastable alloys are the three categories for conventional Ti-based alloys. As shown in Figure 5, the alloy contains commercially pure (cp) Ti and only -stabilizers. By adding a small volume fraction of stabilizing element. The metal alloy most frequently used class is formed by adding a volume fraction of 5% to 40% at TR. A metastable alloy is created by increasing the volume fraction of the stabilizer element/s to the point where it stops transforming into martensite when quenched in a two-phase field. Finally, one-phase -alloys are formed with all -stabilizers. Depending on the alloying elements, martensitic, intermetallic or aluminides (Ti3Al) may exist [16].

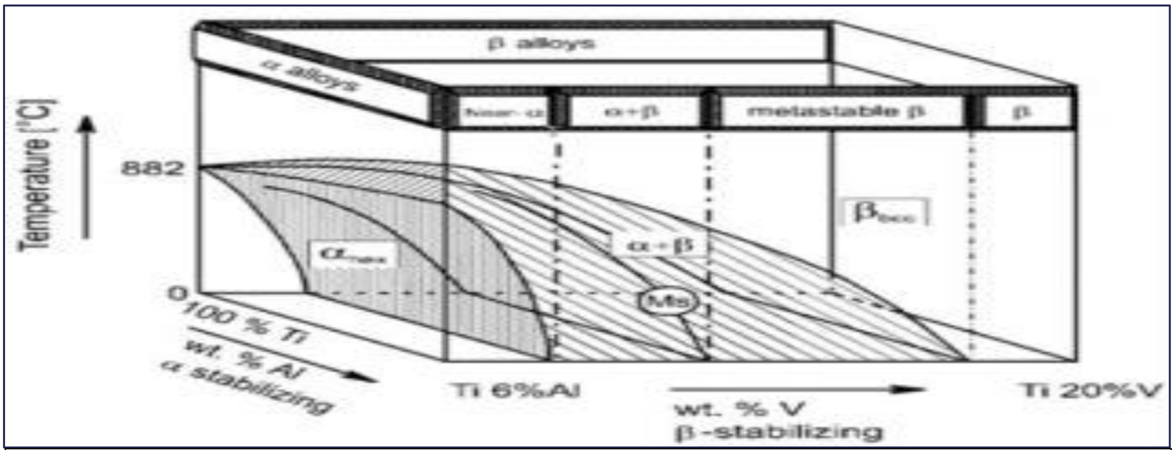


Figure 2.4 *Phase diagrams (3-D), illustrating Ti-alloys classification [16].*

Table 2.2 Demonstrate the behaviour of Titanium based-alloys influence material properties

Table 2.2 *Displays how a material has an impact properties on Titanium based-alloys [16].*

Property / Behaviour	α	α + β	β
Density	Increase	Increase	Decrease
Strength	Decrease	Increase	Increase
Ductility	Increase/ Decrease	Increase	Decrease/ Increase
Weldability	Increase	Increase/ Decrease	Decrease

2.3 Configuration of Ti-6Al-4V

Research showed that "Due to their excellent erosion resistance, titanium alloys are utilised in highly corrosive environments" [21]. The most popular alloy is Ti6Al4V which is commonly utilized in the production of devices for biomedicine [22].

Table 2.3 compares the properties of Ti6Al4V to those of pure titanium, and Table 2.3 shows the alloy's composition.\

***Table 2.3**: Titanium based alloys exhibit various properties at ambient temperature [23,24].*

Property	Titanium	Ti6Al4V
Density [g/cm^3]	4.45	4.26
Hardness [H R_c]	10	30
Modulus of Elasticity [GPa]	115.6	114
Fracture Toughness [$MPa.m^{1/2}$]	70	75

***Table 2.4:** Titanium and Ti6Al4V properties at room temperature [25].*

Aluminium	Vanadium	Iron	Carbon	Nitrogen	Hydrogen	Oxygen	Titanium
6.0	3.0	0.4	0.2	0.04	0.02	0.25	Balance

At 850°C, absolute titanium undergoes phase change in an allotrope from hexagonal-phase to body cantered-phase element. Elements used in alloying have an impact on the transformation temperature. Titanium alloys are classified into four major groups based on their characteristics of metal. [26,27]

- **Alpha – Alloys**
  The stabilisers in these alloys, which are combined with impartial components. Ti-SAl212Sn remains available material with good creep stability and tensile strength at elevated temperatures up to 290°C.

- **Near Alpha-Alloys**
  Alpha and beta phases can be found in these alloys. They exhibit more alpha-alloy-like behaviour, but can withstand temperature ranging from 350 to 600°C.

- **Alpha – Beta Alloys**
  Among these alloys, the most prevalent and widely utilised is Ti6Al4V, which the explain more than 40 percent of aggregate production of titanium [27]. It is mostly employed in heavy strength applications at temperatures ranging from 300 to 450°C.

- **Beta- Alloys**
  Beta phase alloys have excellent forgeability and formability, as well as high density characteristics. At high temperatures, they fall short of alpha-beta alloys in quality.

2.3.1 Tribology Wear behaviour of Ti6Al4V

Ti6Al4V was used in the various composition in order to get best results with reinforcement addition like graphene/cerium oxides/Titanium carbide for better sake [28]. Despite mechanical and chemical properties, the wear resistance is low for the Ti64 alloy. Because of various reasons for this, the first of which is its low resistivity due to shearing effect for increasing hardness features. As a result, the content doesn't effectively resist adhesion, abrasion, and delamination are examples of wear phenomena. The surface oxide's low protection is the other reason for its unfortunate wear resistance. The oxide is formed as a result of substantial more temperatures caused by sliding friction. The reasons stated must be taken consideration for making the composition reinforcement for various alloy elements. [29]

Titanium based composites have apex affinity for oxygen. As a effect of that, a persistent external oxide forms, however, one form of titanium oxide functions as a dense lubricant. [30]. while moving over ceramics and stainless steel, Qu [30] observed a large coefficient of friction may vary at drastic change. The fluctuation thought to be resulting from the development of a transmission layer and its periodic, localised fracture [30]. Other researchers have observed that content is easily transferred by titanium once it slides against all other metal alloys [29,30,31,32].

Titanium's tribological properties when sliding in unlubricated contact include and distortion easily moving materials to such counter face. Outer edge oxidation forms Additionally, this component abides and transmit readily easily to interfaces that are both lustrous and quasi materials. The attraction of oxygen to titanium causes the oxide layer to form. The oxide layer causes severe adhesive wear. [33]

Molinari [29] discovered that as normal force is increased, the wear volume increases. Long's [31] experiments revealed which wears epoxy that occurred Plowing created narrower particles out of the more, and pressure was specifically linked to this process with the more related in the direction of localised dislocation and cracking of asperities. Material transfer from the titanium to the counter surface was also discovered [31]. Long [31] noted that severe tiny plastic transmit and cracking had previously seen in the initial spinning crossing. One such change is important for the Ti6Al4V alloy because it gives excellent lubrication. As a result, the more dribbles, the higher finally coefficient of friction decreases [31]. Long [31] it was determined that now the contact area deformation and transfer titanium's characterization alloys control their friction behaviour. The types of the tribological waste is produced by the interfacial contact surfaces but instead the transfer coating [31].

Nazarenko [34] disclosed that titanium's friction coefficient with some other metallic materials ranged from 0.5 to 0.58 in dehydrated interaction. Straffelin [35] discovered that maybe an lipid oxidation pathway operates at slower slip flow velocity (0.2 m/s) influenced wear.

Molinari et al. [35] investigated the tribo-characteristics a slider neutralise of provisions (trim from chilly bars) at different speeds in addition of loads. The varying actually wear portions as a result of rated load situations. Tribological amount increased as load applied, but no a change in the tribological methodology was observed, even though for either every unique sliding speed test circumstance, a low wear position is present at equal intervals.

At higher loads, contribution action for delamination increases, resulting in an high rate of surface roughness. The impact of sliding distance on wear rate is fewer pronounced. At moving at speeds between 0.02 to 1m/s, a decrease in wear rate is observed, trailed through a rapid shifting into particularly serious metallic metal fatigue wear. [35]

The section's literature describes how sliding interactions produced of Titanium alloys have lesser wear rate. as well as the tribological behaviour for different variation in context with Ti-6Al-4V.

CHAPTER 3

Materials and Procedures

CHAPTER 3

MATERIALS AND PROCEDURES

3.1 Raw material and powder preparation

Ti64 and Graphene platelets with ninety nine percent transparency were used as with the creative output in this study. For Ti64 powders to create such study had the typical molecular structure is 25 micrometer. The present study used multilayer graphene averaging 5 micrometer in diameter and a reinforcement size nearly 2.2 nm on average number. Ti64 illustrations from a scanning electron microscopy (SEM) and Graphene powders are shown in Figures 3.1(a) and (b). The crystals Ti64 captured by Transmission electron microscopy revealed that sphere-shaped, quasi particulate. Those powder particles were uniformly assorted for 8 hours trendy a a ball milling machine with a molar ratio ball to particle ratio. It's spectroscopy images show ball milled powder is given in Figure 3.1(c). The presence of layered Graphene in the matrix is visible in a microscopic image of pulverised marble granulated. As shown in Figure 3.1, energy dispersive spectroscopy (EDS) mapping accustomed to examine the uniform dispersion of layered Graphene into Ti64 powder (d).

Spectroscopy technique is used to analyse the layered Graphene in order to learn more about its a solid foundation. Figure 9 depicts the characteristic peaks that belongs to Graphene. Peaks indicate ties between carbons vibrate in-plane.

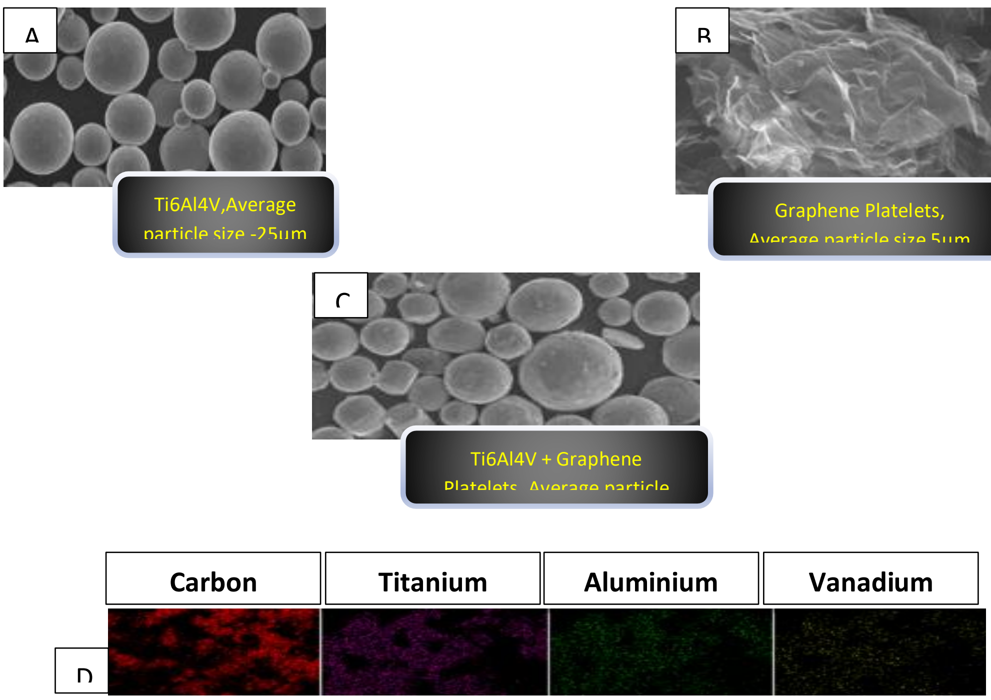


Figure 3.1 *SEM images (A)Ti64 powder (B)Graphene nanoplatelets (C) Ball pulverized mixture powder (D)Energy dispersive spectroscopy plotting results of combination precipitate.*

3.2 Spark plasma sintering for consolidation

The Spark plasma sintering equipment which is in IIT Madras was used to create Ti64 nanocomposites, cab be seen from Figure 3.2. The miscellaneous powder was consolidated using various input parameters in a high-density graphite die (25.5 mm 60 mm). The load used was 45N through a retaining period of 5 minutes to create a metal parts inside a sealed container. with dimensions 5mm long and 26mm in wide.

3.3 Preparation processes of graphene powder in accumulation with Ti-64 composite

Plasma Spark Sintering (SPS)processing, 325 mesh pure alloying element used in commerce powder (ASTM Grade-5) was employed. The powder has a 50 micrometer average grain size on ordinary which summarizes the Titanium powder's contaminant make-up as it had been purchased to be disclosed.

For SPS, Graphite dies were utilised.. The SPS configuration is depicted schematically in Fig.3.2 To determine the processing requirements a data was drawn for a homogeneous coalition. first prepared in one stage or through constant sintering, in which the temperature difference was raised to that of sintered metal and kept in a set duration. For continuous cycle, the The sintering temperature was 1250°C, It was 50 MPa for the compression pressure, and the dwell period 10 degrees was the densification temperature. A vacuum of 6 Pa was used and a central heating rate of 101 C/min was used. After sintering, process of cooling is employed in chamber, the specimen. under vacuum. T1 was assigned to this sample[36]. Similarly, for further samples, names can be assigned accordingly. Samples T1, T2 & T3 can be seen from Figure number 3.2

The Archimedes principle was used to measure the density of the sintered sample. principle after it had been cleaned and polished. During continuous sintering, a relative density of 99 per cent was achieved. As a result of this, a sintered metal procedure in 3 stages was implemented. To attain full densification, repeat the cycle. The procedure can be as follows:

a) Heat the powder from ambient temperature to 580ºC at a rate of 101C/min to ensure that all volatile chemicals are removed.
b) Heating to 850°C at a rate of 25°C per minute for 5 minutes.
c) Heating at the same time from 850° to 1200°C and holding for 5 minutes.
d) In the SPS chamber, heat to 1300°C and hold for 10 minutes before cooling in a t vacuum.

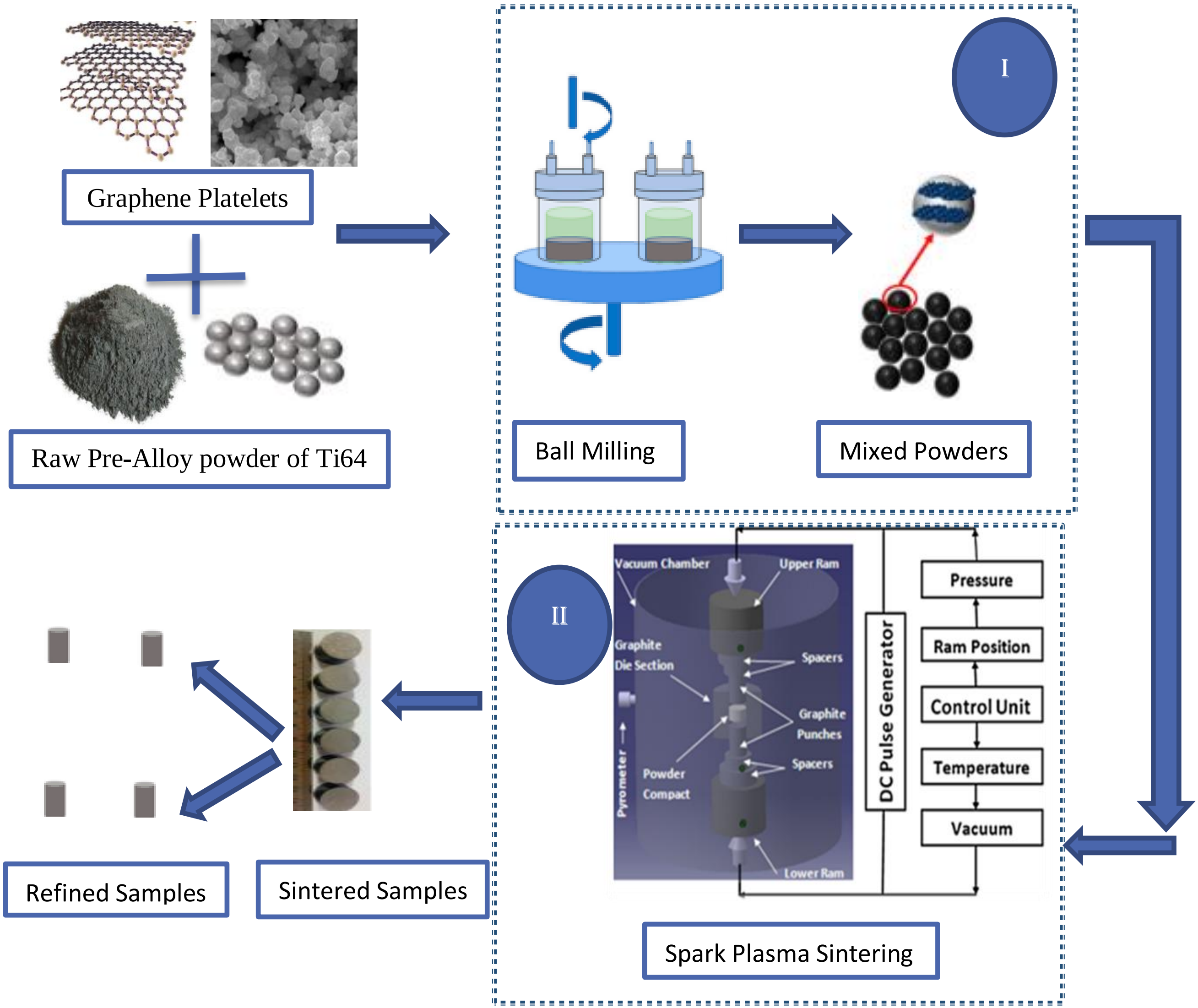


Figure 3.2 *Fabrication process of Ti64 accumulated with multi-layered graphene platelets*

Traditional strategies for structural surface preparation and scraping used to metallographically prepare the sintered samples. Kroll's reagent remained used in the direction of etch polished samples. Light, as well as scanning electron microscopy to examine the sample microstructures (SEM). Each specimen analysed using twin investigation. After SPS processing, the process used X-ray diffraction to ensure there were no negative aspects other than titanium required. Cu Ka radiation was used to record the diffraction patterns. The maximum points and severities were as opposed to those in the Joint Committee on Standards for Powder Diffraction (JCPDS) to perform phase scrutiny. Optical emission was done by spectrophotometry to analyse in terms of its elemental composition sintered samples (OES). Testing for toughness, impact strength, and micro-indentation was performed to measure the characteristics of the as processed material. The requisite refined samples which were prepared from SPS process can be seen in figure 3.3 given below.

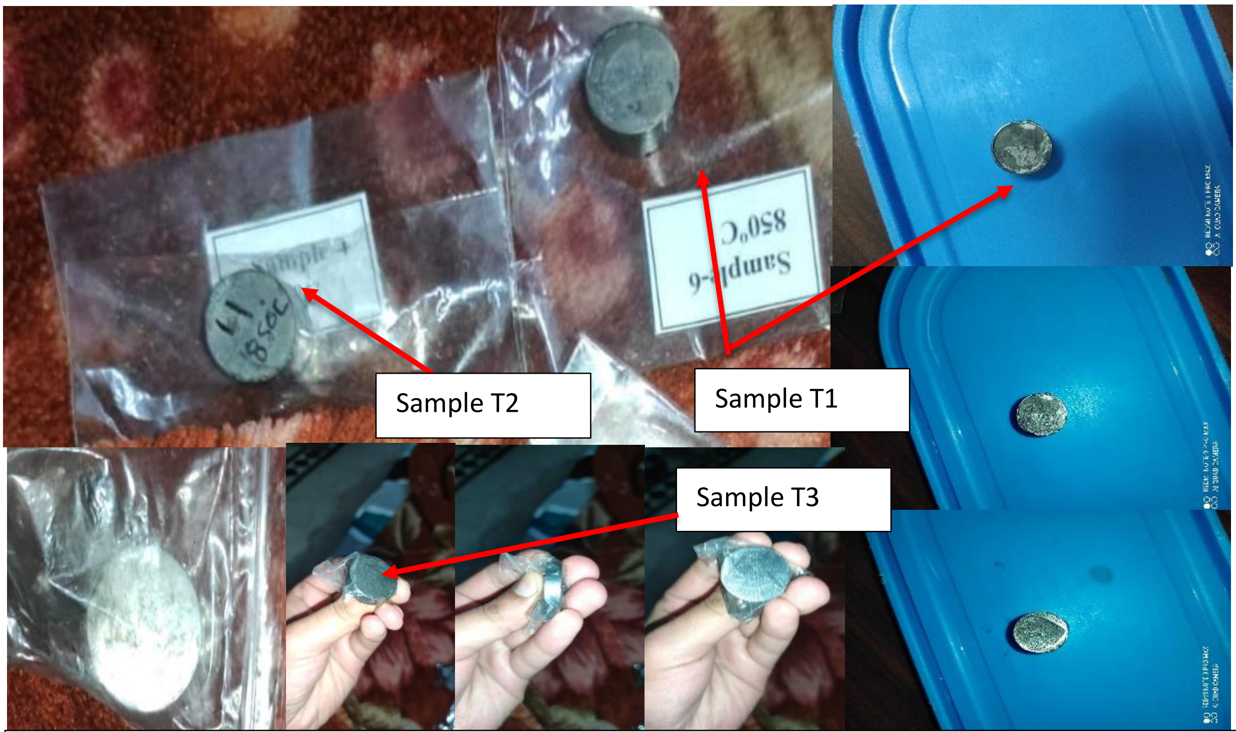


Figure 3.3 *Depicts the Samples T1 , T2 AND T3 prepared from Spark Plasma Sintering*

3.4 Ti64 nanocomposite characterization

SEM images analysed the morphology of using fabricated samples. The Spectrometry specimens were refined with micro structural techniques followed by a plunging technique. Energy dispersive spectroscopy was also implemented in sample basic scrutiny. XRD stayed in the use to investigate the examination of sintered samples' phases. XRD results were analysed using a Cu-K radiotherapy is used by the X'pert Pro microplate reader. In order to analyse the XRD results, a scanners rate of 4°/min in the 20-90° point range was also used.

The sintered Titanium matrix composites phase and configuration were determined using an X-ray diffraction technique. Figure 3.4 shows the Sintered SPS specimens for XRD patterns that confirm the presence of Titanium, Aluminium, Vanadium, Carbon, Iron and Titanium carbide. The peaks were corresponding with the joint peak for Figure 3.4 (a). JCPDS Card numbers 01-089-5009, 01-089-02,769, and 03-065-4776 are issued by the joint committee on powder diffraction standards (JCPDS). Figure 9(b) shows TiC and C peaks that were matched to JCPDS card numbers 01-065-0966 and 03-089-8492, respectively. At the Ti/layered graphene interface formation was detected. The titanium again from base alloy is indicated by a crest at 2°degree of 40.2987 and 40.3157 in the Xrd analysis of composites Ti64 and Titanium with layered grapehene mixture nanomaterials. Resulting in the formation of grains. The XRD form with the graphene reinforcement contains sample revealed carbon peaks. The presence of crystalline TiC phase in Ti64 is demonstrated by the addition of varied graphene percentage.

Due to the withholding of graphene platelets at that much apex temperatures suggested that there is an interlayer effect among matrix composites with the graphene platelets which could be measured by refining layer superiority. The evidence used is provided mostly by findings of s current learning. The precision machined nanostructures contain Titanium carbide peaks that were less penetrating, indicating that Interlayer response seemed to be well situated. The requisite XRD pattern revealed that The Ti elemental peak frequency and location seemed to be different. The presence of graphene could explain this distinct crystal structure. Thus in present research, Ti64 in accumulation with graphene powders quickly liquefied, then helped solidify, affecting grain forming as well as resulting in reaches a maximum various crystalline phase.

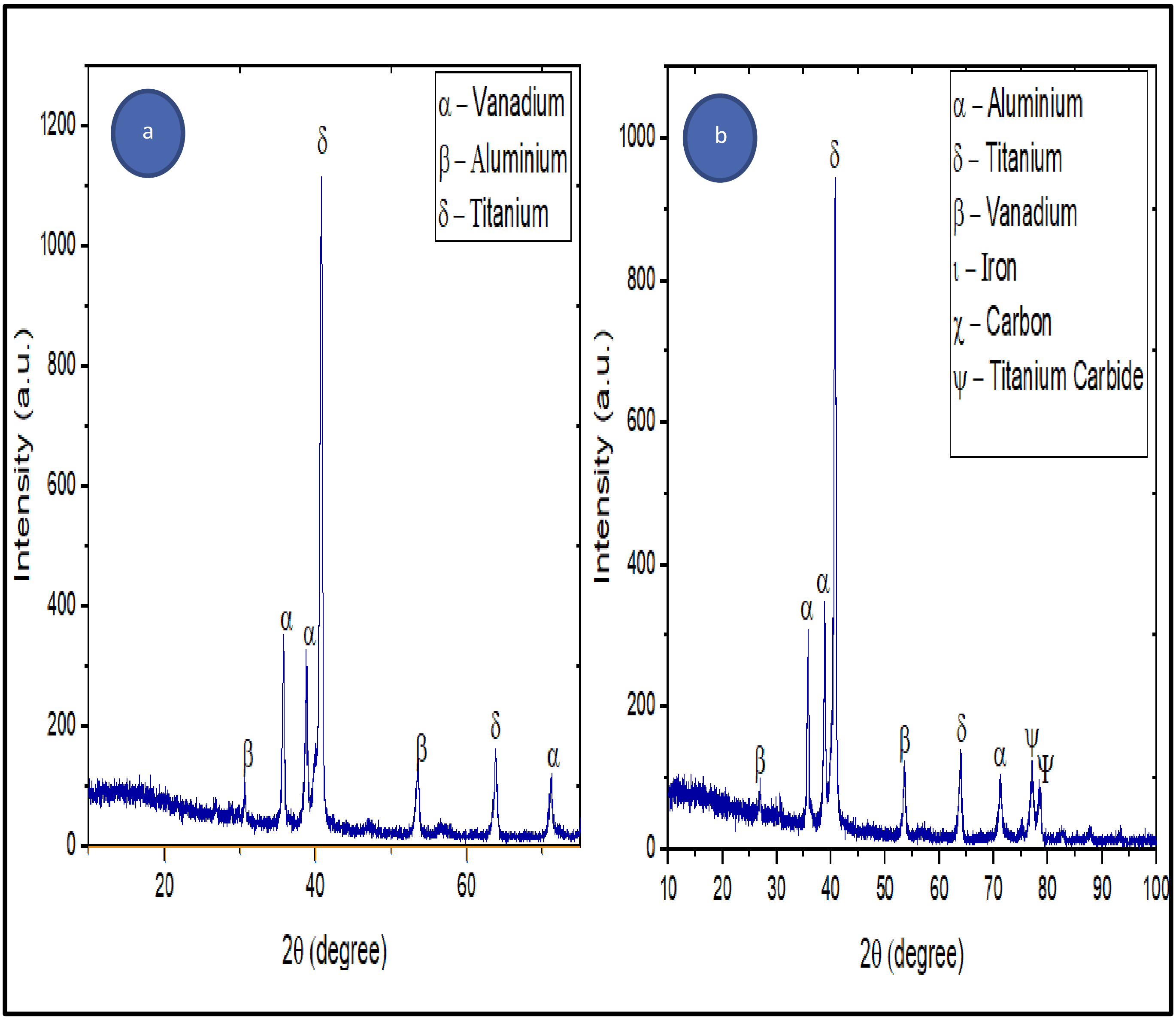


Figure 3.4 *Sintered Ti64 alloy X-ray Diffraction pattern and sintered Ti64/MLG composites (a) and (b).*

CHAPTER 4

Testing

&

Experimental Procedure

TESTING AND EXPERIMENTAL PROCEDURE

4.1 Energy Dispersive Spectroscopy (EDS) spectra

Figure 10(a–c) depicts an spectroscopic analysis using energy dispersions analysis of the Ti6Al4V, Ti6Al4V with 0.8% of graphene and Ti6Al4V with 1.2% of graphene platelets reinforced composites. The spectroscopy analysis clearly shows that Peak was observed in oxygen and carbon were noticed. The EDS investigation strongly suggests that aluminium TiC particles are present in the composites. As a result, the SEM results indicated that the process resulted in the successful incorporation of ceramics Ti64/TiC -reinforced Ti-matrix composites.

Figure 10 shows the Ti6Al4V alloy alone and Ti6Al4V alloy reinforced specimens' EDS ranges. Only Aluminium, Vanadium, and Titanium elements were found in the volume percentages of 5.4 percent, 4.0 percent, and 90.5 percent, respectively, in an EDS investigation

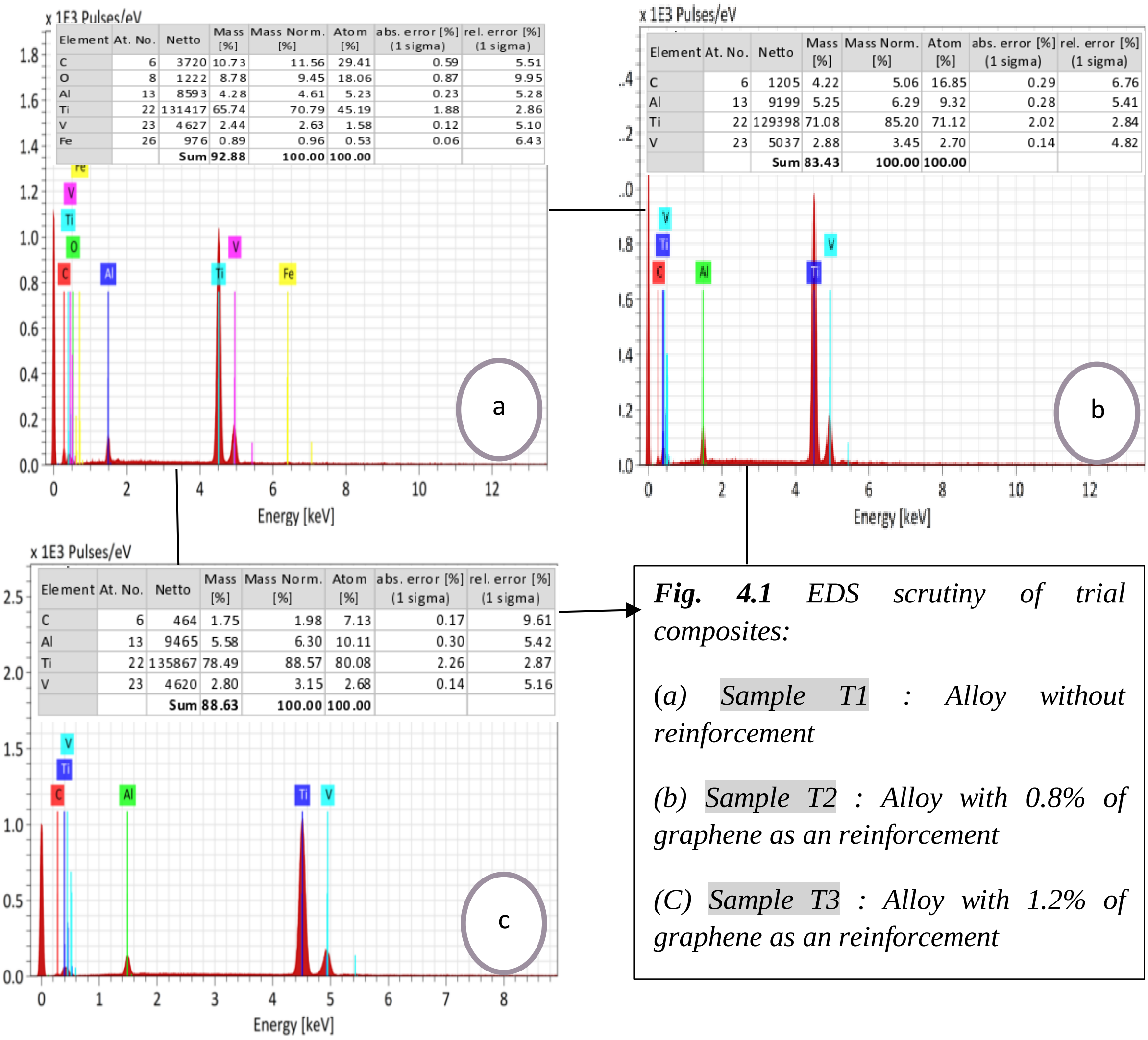


***Fig. 4.1** EDS scrutiny of trial composites:*

(a) Sample T1 : Alloy without reinforcement

(b) Sample T2 : Alloy with 0.8% of graphene as an reinforcement

(C) Sample T3 : Alloy with 1.2% of graphene as an reinforcement

of a sintered Ti64 alloy sample. Aluminium (Al),Vanadium (V), Titanium (Ti) and Carbon (C) elements were found in mass fractions of 5.25 percent, 2.88 percent, 71.08 percent and 4.22 percent respectively, in a Ti64 Grade 5 alloy composite sample T1 .For sample T2 there is Aluminium, Vanadium, Titanium, 0, Fe and Carbon elements were found in frame segments of 4.28 percent, 2.44 percent, 65.74 percent, 8.78 percent, 0.89 percent and 10.73 percent respectively, in a Ti64 alloy composite sample T2. The mass fractions of aluminium, vanadium, titanium, and carbon in the Ti64 alloy Grade 5 composite sample were 5.58 percent, 2.80 percent, 78.49 percent and 1.75 percent respectively.

The existence of requisite composition of various elements is indicated by the peaks depicted from EDS graph i.e. from Figure 4, whereas the peaks of Titanium, Aluminium, and Vanadium are assigned near the Ti64 alloy matrix. With increasing reinforcement content, can clearly depicted from sample T2. The presence of reinforced elements Ti64 alloy composite specimen is confirmed by EDS spectra.

4.2 Microhardness Testing

Another name of micro hardness testing is indentation hardness testing. The process involves indentation at various levels up to 500g and thus indentation depth (70 – 100 µm) gives the value of hardness at a particular point in the specimen. Generally, Vickers hardness testing machine is used in it. Along with Vickers hardness testing machine a square-shaped cut diamond indenter based pyramidal shaped. A ratio produced by diamond shaped indentation between the long and short diagonal is 7:1. With the help of optical microscope resultant indentation is measured. The optical microscope is calibrated as the indentation size. Large load as possible is used in it [9]. Test needs to be carefully controlled and strain free specimen is used in it. The diamond indenter is indented at maximum load and lowered slowly at the rate of < 1mm/min.

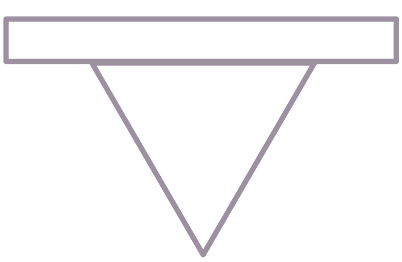


Fig4.2 *Diamond indenter*

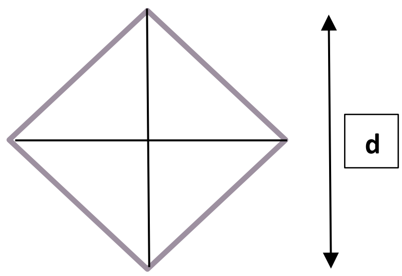


Fig4.3 *Pyramidal indentation*

The specimen microhardness test is very much important in order to forecast the strength analysis for the requisite composite. Table 2.5 clearly depicts the work composition in context with the density values and void content percentage. After proper examination of the microhardness values which acquired that the hardness values are increasing as the amount of graphene percentage as a reinforcement in context with Ti-6Al-4V.

Table 2.5: Theoretical and experimental densities are compared in this study.

Material Composition	***Theoretic density (g/cm^3)***	***Investigational density (g/cm^3)***	***Comparative density***	***Void content (%)***
Ti64	4.430	4.357	98.64	1.22
Ti64/0.8G%	4.414	4.385	99.74	0.43
Ti64/1.2G%	4.413	4.381	99.85	0.24

Figure 4.4 *Vickers Hardness Tester (TIET, Patiala)*

(Table 2.6)

Specimen No.	Trail 1 Test	Trial 2 Test	Trial 3 Test	Average Hardness
T1	521.9198	474.282	516.8405	504.34
T2	478.7458	400.085	4321.9872	439.4154
T3	380.2492	448.7649	465.5396	431.5179

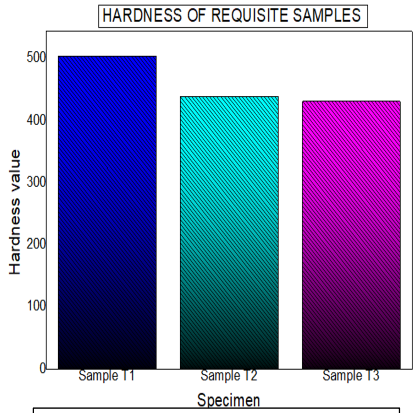


Fig4.5 *Average hardness plot*

A cylindrical specimen of Ti-64 of different composition that is 3 samples were made to get the hardness values for each one of it. Each specimen had dimensions of 45 mm and a thickness of 5 mm. To get rid of the abrasion caused by sectioning and grinding so in a series of steps, finer and finer abrasives were applied. A 120, 240, 320, and 400 mesh grit series was used. For 3 to 6 minutes, apply in stages. Between each other, in order to remove the previous contamination, the specimen was washed and medium for grinding eight-inch polishing wheels of the diameter of 200-600 rpm and a speed range of 200-600 rpm were used. The indentation tests were carried out in conjunction with Table 6 lists the available facilities. Table number 6 depicts the trials in which the requisite specimens had gone through by indentation for Vickers hardness test. It is evident from the table that, as after the three number of trails it can be acquired that specimen "T1" has more hardness that is 504.34 HV_{500} than the remaining ones. From the remaining samples it could clearly an indication of the rigidity value of specimen "T3" is less i.e. as compared to both the samples and specimen 431.5179 HV_{500} and the specimen "T2" is having 439.4154 HV_{500} which is somewhat in between. It is evident from the bar chart also that the hardness values at 500gms load and dwell of 20 seconds is showing the continuously decreasing trend for their requisite material composition.

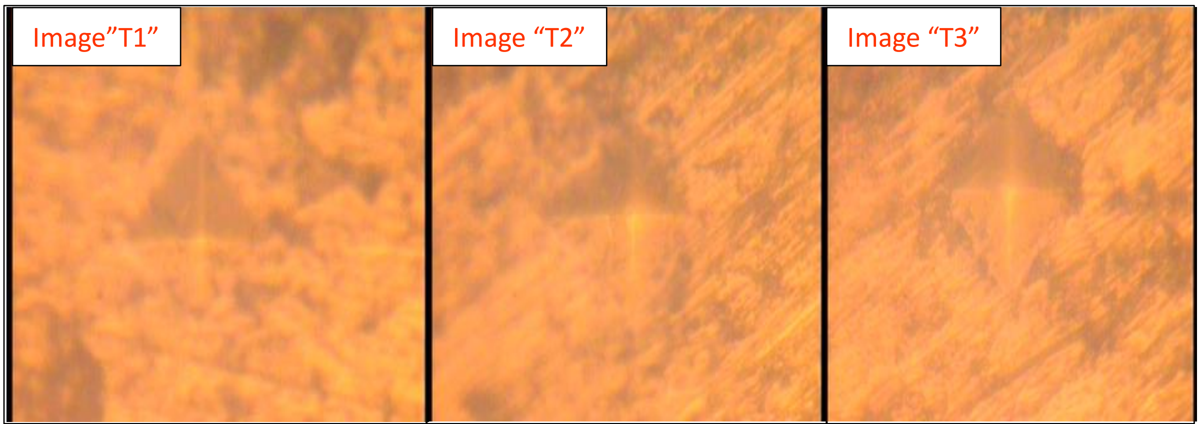


Figure 4.6 *Represents the Vickers hardness indent at load of 500 grams for 20 seconds dwell*

It is evident that from figure 8 , i.e. there is very minute or negligible indent spot which further giving a sign that the material is very hard in nature due to its composition that's why the indent spot cannot be recognized easily. On the other hand for the remaining samples the indent spot is fairly presenting itself up to certain depth of extent up to the material nature of hardness due to its composition. In accordance with the image which came from Vickers hardness software its estimating that specimen T1 is pretty hard material as compared to the sample T2 and T3.

4.3 Wear Tests

In order to conduct the Tribology evaluation, the specimens were subjected in the form of cylinder pins of diameter 8 mm and length 10 mm primed for the wear process. On a general tribometer , sliding wear tribological tests were performed and the results using only a pin-on-disc setup. The steel reverse edge plate was made of 200 HV Vicker's durability steel. Ever other specimen was rooted using emery paper of different grades even before tribological test began. Every analysis was conducted over a 2000 m sliding distance. Following the conclusion of the application of the load, specimens and the counter face plate were sanitised before being oxidised. All tests were performed twice in order to ensure validity of the results. The damaged samples were again examined through the use of a scanning electron microscopy (SEM) for look for cracks and other wear-related effects.

Pin-on-disc experimental arrangement, Titanium alloys with reinforcement pin and alumina disc's tribological outcomes was examined in this study. For both pin and disc, the starting The bought ingot measurements seem to be 50 x 50 square centimeters. Wire EDM was used to manufacture the pin. A profilometer was used to measure the pin's roughness following machining, friction values ranged from 280 to 60 nm. The annealed rods were used to make the test pins, which were made of Grade 5 titanium alloy Ti64. Wire EDM is used to cut the pin. The flat end of the test pin [37].

An analysis of titanium alloy's chemical makeup was performed. in order to determine the level of the substance obtained, the outcomes are presented in table 2.7

Table 2.7 *Formation of chemicals of Sample T1 Titanium Alloy (Ti-6Al-4V)*

(varied % of graphene)

Element	Carbon %	Oxygen %	Aluminum %	Titanium %	Vanadium %	Iron%	Graphene%
% by mass	10.73	8.78	4.28	65.74	2.44	0.89	1.2

Table 2.8 *Formation of chemicals of Sample T2, Titanium Alloy (Ti-6Al-4V)*

(varied % of graphene)

Element	Carbon %	Aluminum %	Titanium %	Vanadium %	Graphene %
% by mass	4.22	5.25	71.08	2.88	0.8

Table 2.9 *Formation of chemicals of Sample T2, Titanium Alloy (Ti-6Al-4V)*

(varied % of graphene)

Element	Carbon %	Aluminum %	Titanium %	Vanadium %	Graphene %
% by mass	1.47	5.63	78.98	2.87	-

Table 3.0 *Combinations of parameters for testing contact resistance*

Sr. No.	***Weight (N)***	***Interaction Force***	***Moving Distance***
1	10	0.496	500
2	10	0.496	1000
3	10	0.496	1500
4	10	0.496	2000
5	10	0.496	2500
6	20	0.744	500
7	20	0.744	1000
8	20	0.744	1500
9	20	0.744	2000
10	20	0.744	2500
11	30	0.992	500
12	30	0.992	1000
13	30	0.992	1500
14	30	0.992	2000
15	30	0.992	2500

The disc is placed horizontally Figure depicts the pin-on-disc test rig. 16 and as the pin affixed to the pin holder. The disc and pin come into contact in a vertical direction. an adjustable speed control system and a Servomotor were used to rotate the disc at a desired rotational speed. The studies were carried out in a dry environment with a relative humidity of 35%, a room temperature of 27°C and 1.01 atmospheric pressure. The trials were conducted in the following circumstances: (i) load: 1kg , 3Kg , and 5Kg (ii) sliding speeds of 1 m/s, (iii) 2000 m moving path length, and (iv) the surrounding environment. Prior to each test, contact surfaces were acetone-cleansed, and an automated scale was used to weigh them scale with a 0.001 g accuracy. The pin and disc were ultrasonically That after laboratory exercise, the surfaces were started cleaning in acetone, and the heaviness was measured. By comparing the pin and disc loads prior to beginning the research, it is possible to determine the loss of weight of the pin and disc.

Pin specimens were put through their paces on method involves tribological apparatus. The analyser for pin on disc wear really does have a total 150 micrometers disc diameter and a various holders created for various pin sizes and shapes. The test holder can accommodate a pin with a diameter of 8.1mm and a height of 30.5mm. A computer system was used to keep track of durability, friction coefficient, and co-efficient of vibration.. WINDUCOM is the data recording software. Technology called WINDUCOM was provided by the manufacturer of pin-on-disk test rigs contains test details such as the number, duration, and rate of experiments. Here an experimental set-up of tribometer in order to make a pin an pipe of same diameter of the sample is cut out and the samples get accumulated inside it for wear tests. We have a moving platform through which disc is inserted . There is a controller where weights and load actuators can be controlled from their defined positions. All the wear and co-efficient of friction values are calculated from wear and friction monitor which adjusts the timings and speed through which sample which have to run. In context with this an desktop is also tethered in order record the coefficient of friction value which is presented in WINDUCOM software as a graphical image[8].

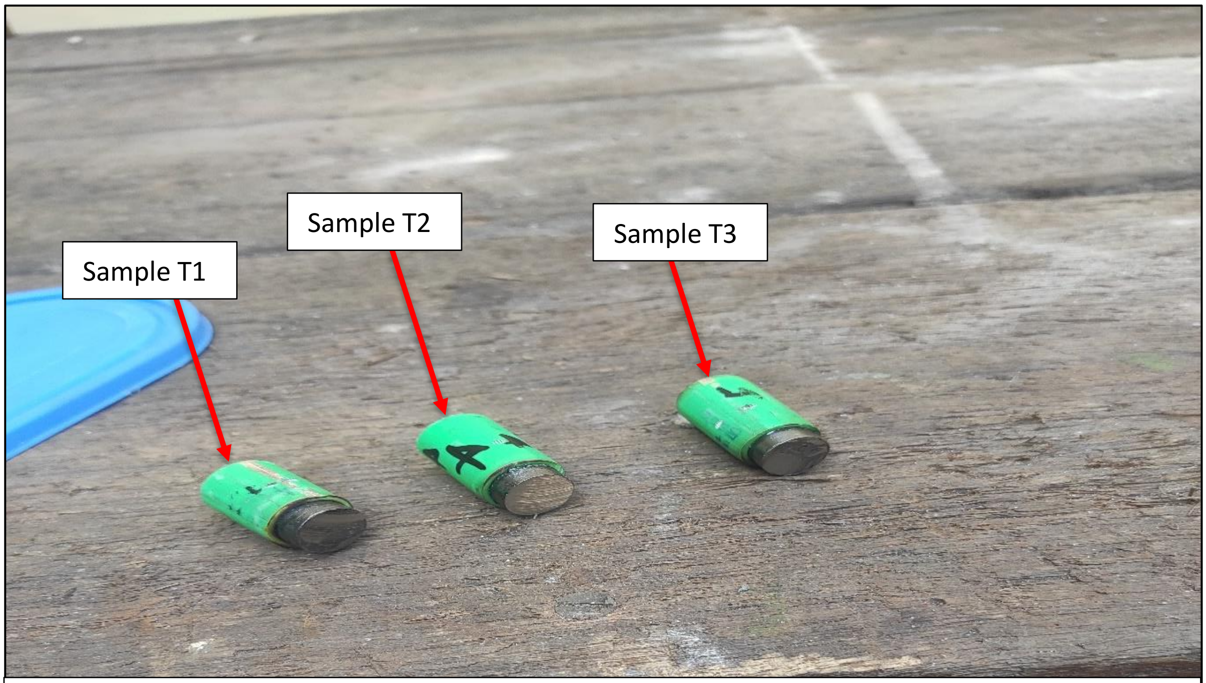


Fig. 4.7 *Samples of Ti64 of different composition is incorporated in the pipe for tribology testing*

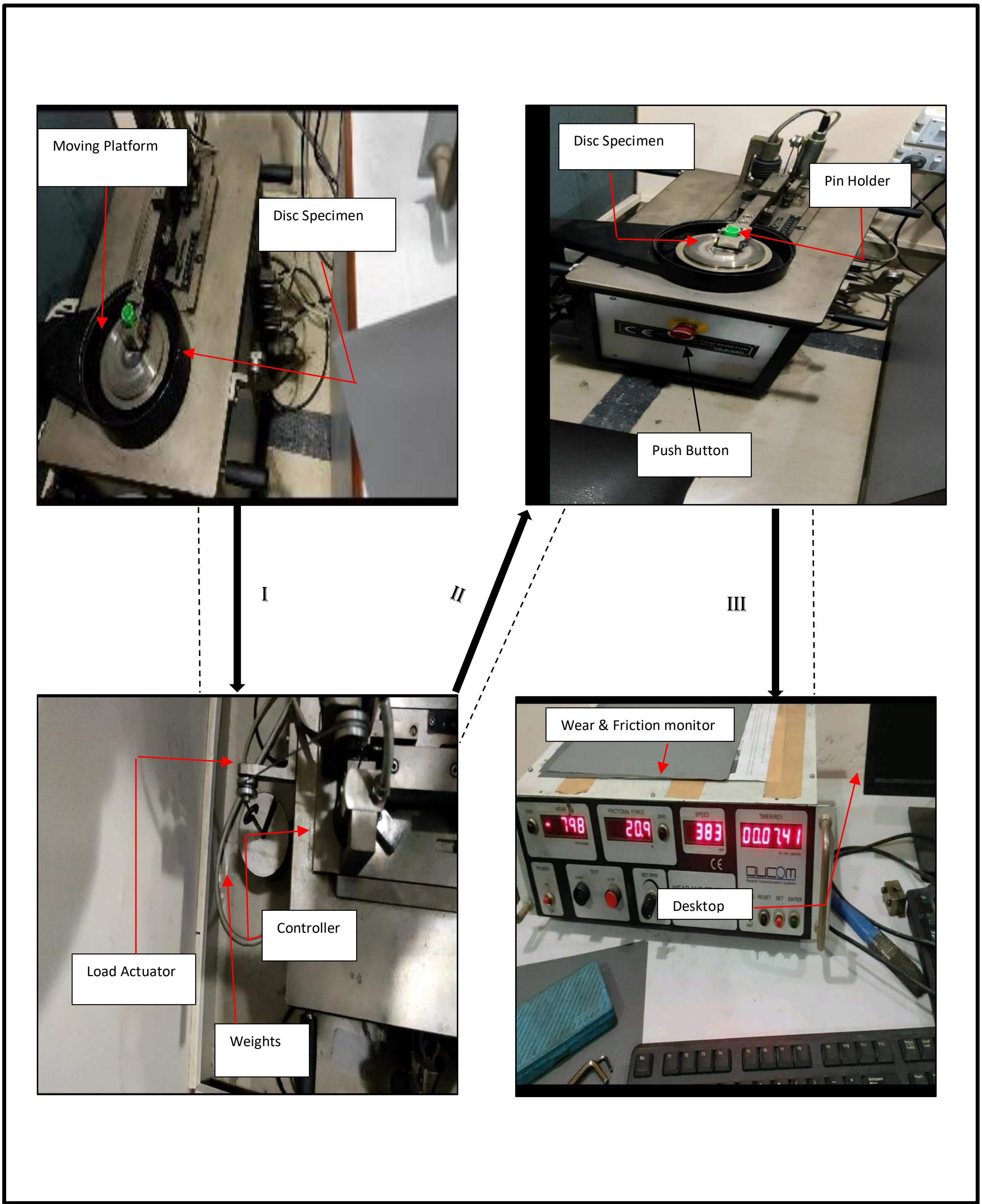


Fig. 4.8 *Experimental test setup of Pin-on-disc in Tribology lab at TIET, Patiala*

4.4 Results and Discussions

4.4.1 Hardness

The stength of the base material Ti-64s as well as the hardness of all other hybrid composite samples. Hardness testing results show so the resilience of composite material specimen Carbon and Iron as just a supplement is greater than that of composites without Iron i.e. Fe element. It's also obvious based on the outcomes that through which explicate 0.89 weight percent of Iron (Fe) adding a component, the hardness value was slightly more, and with 10.73 weight percent of carbon compound, the hardness value increased slightly more, and when that composition arises, the hardness value increased dramatically when versus the foundation alloy and remaining composite samples.

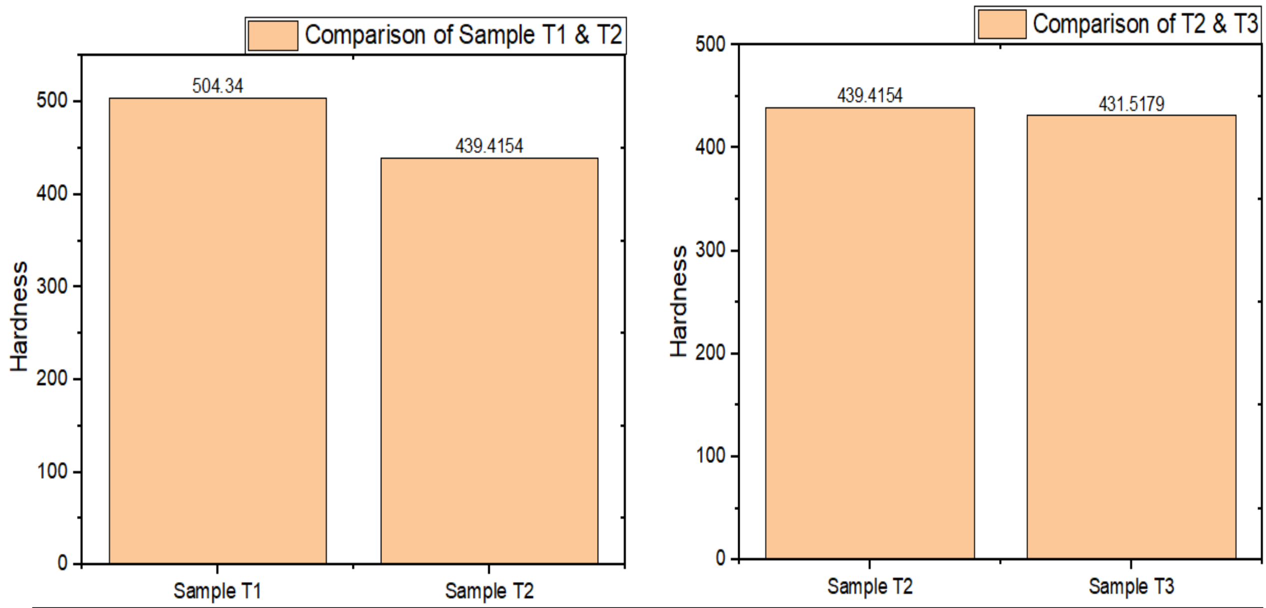


Fig. 4.9 *Samples comparison bar chart between T1 and T2 as well as T2 and T3*

As from above figure number 10 it is clearly depicted that the sample T1 is having more hardness value due to more graphene percentage that is 1.2 % and having more carbon content in it. If we compare sample T1 and T2, the prior sample T1 is having more graphene percentage than T2, where T2 is having only 0.8 % of graphene in accumulation with Ti-6Al-4V. In same context, due to no graphene addition in sample number T3 so that its hardness is far low as compared to both the remaining samples.

4.4.2 Wear Testing via Tribometer

According to Fig. 19(a), Up to a distance of 500 m, all samples' wear rates were predominately high. Following that, Wear was seen to sharply decline. in the Ti-64 sample T3 up to a distance of 1500 m. After that, the pattern in wear rate stabilises. In contrast, that very same trend can be seen in sample T2 with a lower overall wear rate. After 500 m, the insertion wear rate wasn't particularly steep, and it stabilised after 1000 metres in every composite material. At a load of 10 N, the wear rate of sample T2 laminate was 43 percent lower than that of T3 sample. Whereas Ti-64 sample T1 with the highest hardness value shows an 88% wear has improved rate. Figures 19(b) and (c) depict the wear pattern for every specimen at 30 and 50 N loads, respectively. Graph depicts the sample's wear performance at 10,30 and 50 N loads, respectively. At high load values, the aggregate implications of friction coefficient, lowering the general effectiveness of the tests.

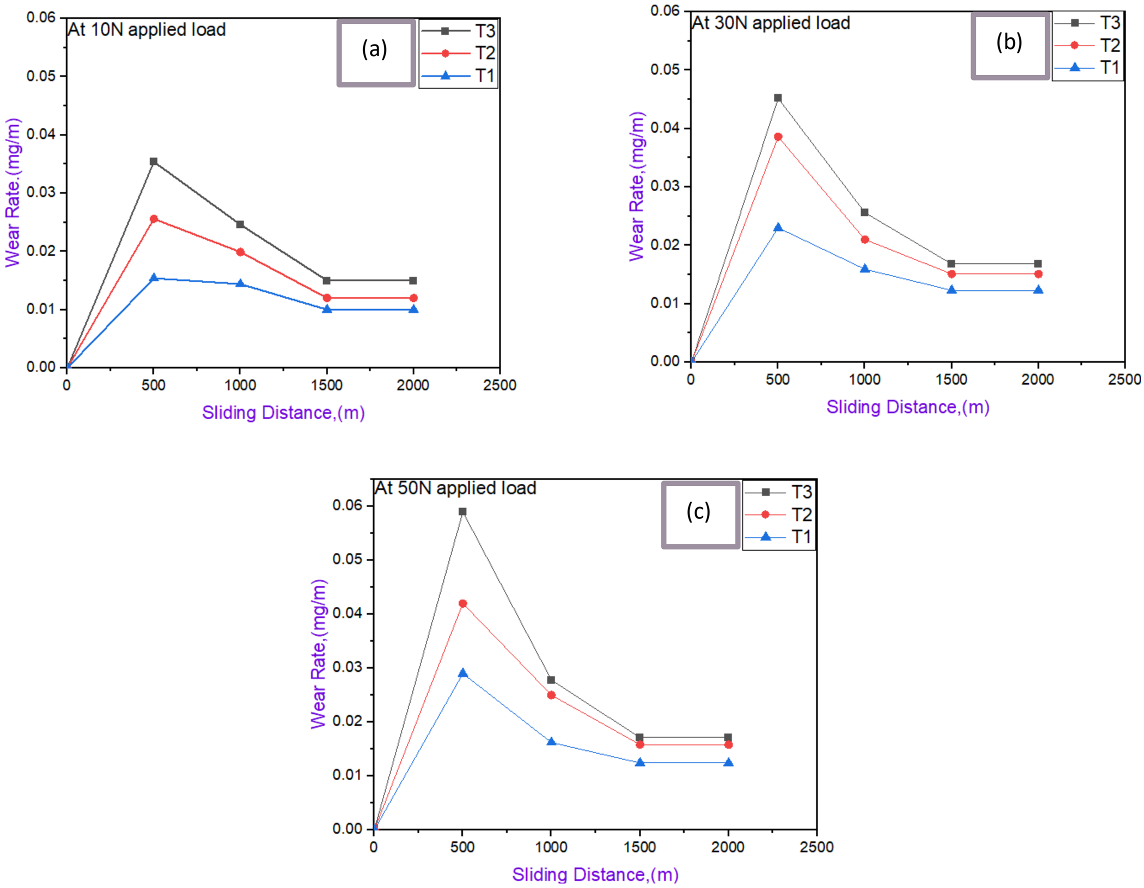


***Fig. 4.9.1** Progressive wear rate plots for Ti-64 samples T1, T2 &T3 at speed 1 m/s (a) load 10 N, (b) load 30 N, and (c) load 50 N*

4.4.3 Wear Track Surface Morphology

The SEM micrographs were used to evaluate the materials' damaged surface areas and and EDS to recognize the multiple techniques while the wear assessing of the Ti-64 alloy composites. Studies revealed that, whereas the bulk abrasion percentages titanium in addition the remaining ones seemed to be differed, the sample exhibited nearly similar tribological methods. As a result, the various the wear mechanisms mentioned here independent of the sample. Everyplace there is variation, it was noted to get analysis. Debris analysis is a critical component of evaluation of surface roughness. Debris evaluation is performed towards determine the capacity of oxide layer on surfaces during a wear test [38]. Debris gathered for this observation, Figure 20 shows a SEM image of debris. As shown in SEM micrograph of figure 20, the most severe effects included abrasive wear, ploughing, and plastic deformation. dominant wear mechanisms in a composite sample consisting of Ti-64 mixed reinforcement during a load of 10N, 30N & 50N and a sliding velocity of 1m/s. The worn-out surface of the Titanium alloy Ti-64 is depicted in Fig. 20(e) & (f).

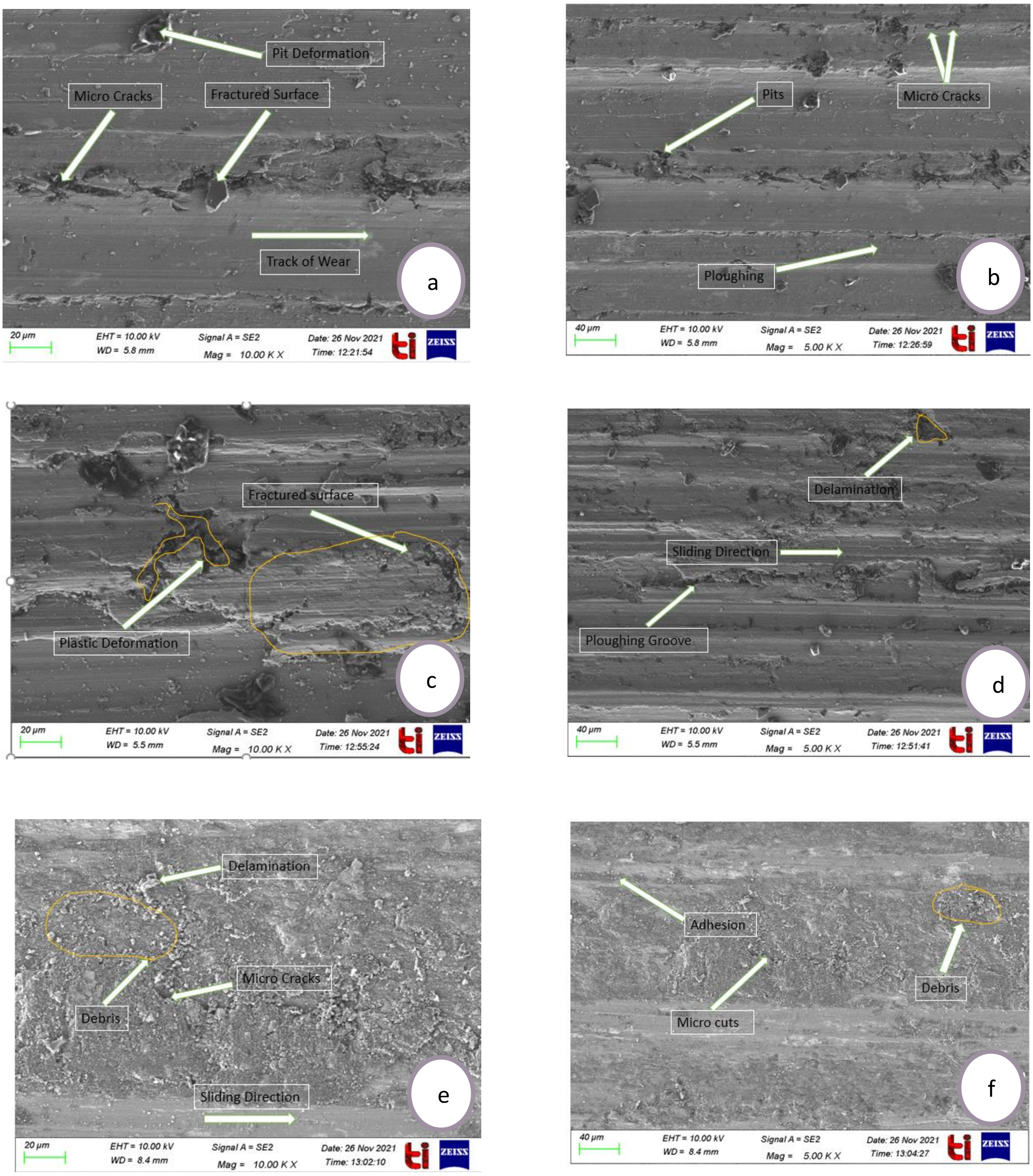


Fig.4.9.2 *SEM images of wear specimens at sliding velocity 1m/s which is sample T1 for (a) & (b),sample T2 for (c) & (d) and sample T3 for (e) & (f) images respectively*

4.4.3 Material crystallinity via X-ray Diffraction (XRD)

X- Ray diffraction is a procedure to capture whether the material which is used for study is crystalline or amorphous. In order to define the material crystallinity , if the material is crystalline then the graph from XRD will show the atoms are arranged in a periodic order which is shown in figure 14. In context with that if the material shows it is crystalline material then it will give a sharp peak. Sharp peak in X-ray diffraction generally means it is crystalline otherwise amorphous. X-ray diffraction is a useful method for determining the properties of hybrid composites composed of various powder mix elements of Ti-6Al-4V. Each XRD pattern plot depicts the phases formed in samples with varying percentages of reinforcing elements. In the majority The highest elevation was seen in cases using a magnitude of 2.. Figure 14 depicts the different designs for varying compositions of samples T1 , T2 and T3 respectively . The huge spikes correspond toward the parent metal because the parent material is primarily made up of titanium in matrix form. XRD analysis also showed that the lesser peaks in hybrid composites correlate with the existence of varying phases. To determine the proper synthesis of the material it should match with the Joint committee on powder diffraction standard (JCPDS) file, if it gets matched then it means material is desirably synthesized material[39].

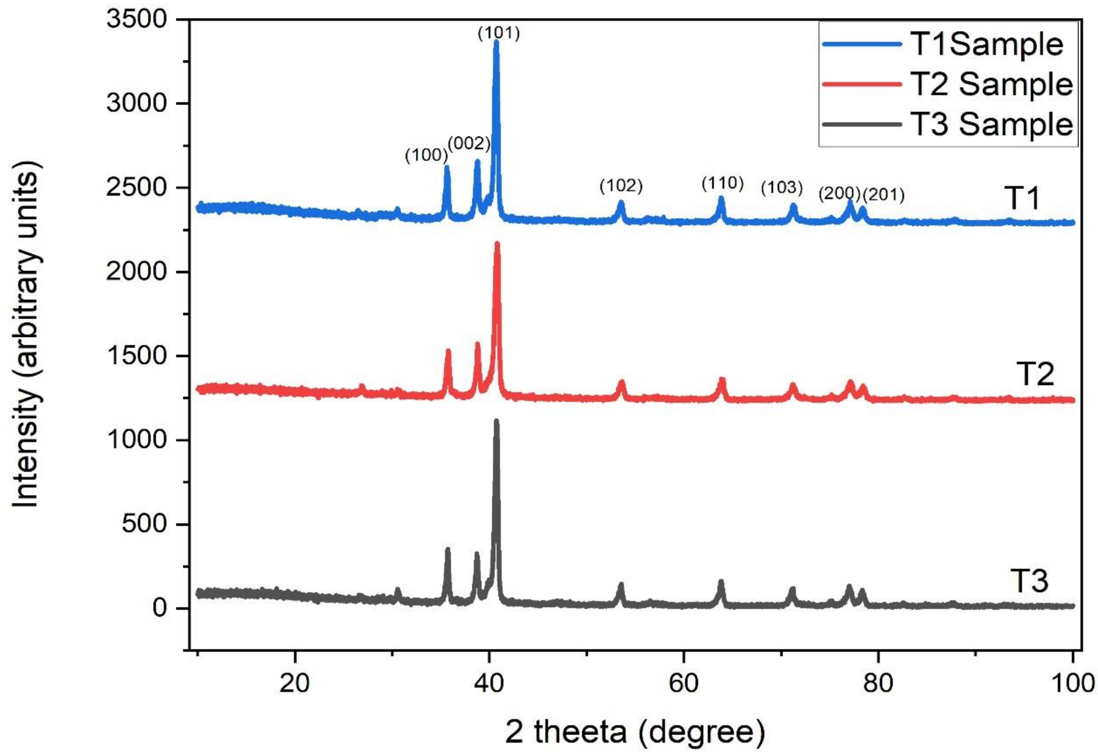


Fig.4.9.3 *XRD graph of samples T1 ,T2 & T3 containing different amounts of Ti-6Al-*

4.5 Conclusion

- Microhardness measurements from Vickers's hardness test for the three materials were slight differ in their hardness values. Microhardness measurements show that the Ti–6Al–4V alloy of sample T1 is extremely hard compared to remaining other two samples because of element addition of Fe for 0.85% of mass percentage and the obvious reason of graphene platelets addition that is 1.2 % of mass percentage.

- A rise in the wear rate corresponds to a normal imposed weight but after certain period of time that is after 2000 m sliding distance wear becomes stagnant. Sample T3 shows an 88% of improvement in wear rate from 30N to 50N. The thing was discovered that the greatest loss of weight occurs at a greater load values. Furthermore, as the normal load decreases, so does the wear rate.

- SEM micrograph images shows the The most severe effects included wear rate, ploughing, and plastic deformation. dominant wear mechanisms in a composite sample consisting of Ti-64 mixed reinforcement at a load of 10N, 30N & 50N and a sliding speed of 1m/s.

- Proper refined peaks can be seen from XRD data in context using the tools X'Pert high score pro so that required miller indices were calculated for identification of lattice size and lattice strain values.

- Improvements in aircraft fuel efficiency are driving up demand for titanium in airframes and engines. Each titanium material is chosen for an aircraft according to its desired use. The requisite accumulated with graphene can be when formability is required for aircraft valued highly.

- The review of titanium alloys with requisite reinforcement was the topic of this project report. The properties and applications were enhanced as we use the graphene platelets in to enhance tribological characteristics. Ti-6Al-4V received particular focus. The aeronautical, automotive, and bioengineering disciplines received the most attention in terms of application. The key findings are displayed in the section below.

  - In general, the tensile strength of titanium materials ranges between 250 MPa for pure titanium and 1450 MPa for close composites, although the values for Ti- 6Al-4V choice between 800 and 1150 MPa.
  - Ti-6Al-4V's flow stress rises significantly as strain and strain rate increase, However, it falls as the temperature goes up.
  - This is employed in a variety of applications, including systems and parts, and are typically chosen for their corrosion resistance and/or strength. However, for biomedical applications, biocompatibility is also a crucial requirement.

CHAPTER 5

Applications and Future scope

CHAPTER 5

APPLICATIONS & FUTURE SCOPE

5.1 Application Potential

Pure titanium, also known as elemental titanium , the tensile modulus is low and density, a reasonable resilience, decent corrosion resistant in a variety of elevated reaction kinetics in certain surroundings for wide variety of components. It is also numerous applications in variety of demanding industries like aircraft industry, auto parts, and biomedical industry [40].

Aerospace applications

- Titanium materials have found widespread use in the aerospace industry, especially as in avionics or propeller mechanisms, such as when make up 36% and 7% of total weight, respectively.

-The stronger and more heat-resistant alloys, in limited quantities with high requirements for mechanical performance, such as engine components and airframes.

- Creating new alloys with increased strength and higher service temperatures has proven to be the biggest challenge.

Automotive applications

- With the introduction of F-1 racing cars in the 1980s, titanium materials were first used in the automotive industry, mostly in machine components.

- Nowadays, these are frequently castoff to make connecting rods, retainers, inlet and outlet ports, and in limited quantities, with bulk reduction is among the principal advantages.

- There are several new alloys being researched for use in automotive components right now, including lots of background features.

5.2 Future Work

To obtain the necessary knowledge of the material behaviour prior to applying in aerospace and biomedical applications, predictions of mechanical and tribological properties can be made. Due to titanium's widespread use across all industrial sectors, it is anticipated that in the near future, industrial demand will grow faster than the rate of global GDP.

CHAPTER 6

Industrial Oriented Project

CHAPTER 6

PREFACE

For the electronics appliance there is huge demand in order to conquer the daily routine tasks which may help the individuals to do the necessary tasks effectively. For that purpose, LG Brand has made a big name in the current scenario.

Comparing LG's growth accomplishments to those of companies like Havells, Blue Star, Bosch, etc., LG's growth accomplishments are very high. Instead of using these businesses, LG has its own NABL (National Accreditation Board for Testing and Collaboration) lab, which is a great way to ensure that the manufactured goods meet the required standards for quality.

The refrigerator, washing machine, microwave, wall fan, and water purifier filter are all produced at the LG India plant in Noida. All of these are produced under one roof, with the designing falling under the R&D (Research and Development) Sector. Prior designing and assembly tests were completed using software like Solidworks, Catia, and Proe for initial drawings, and assembly and load tests were completed at Ansys for accurate and thorough analysis of every part before final production. The expansion of LG combined with an increase in global employee numbers has led to a tendency for the LG community to be regarded favourably in order to secure future endeavours.

In this electronics appliance company, there is simply a fantastic opportunity to learn various work skills related to an engineering background. Therefore, it was a pleasure to learn the difficult tasks along with engineering-related problems, which enabled one to grasp a clear handout in mind for the identification of the necessary skills.

INTRODUCTION

With regular key inputs which leads to the growth of employee in their allocated roles which the supervisor had assigned. In order of that, completetion and initiation will come from the training to a professional localised skill. LG India, board members are now clearly diversify to select the knowledgeable and hardworking employee which further acts as a support to the company to get the desired results of production whether it will be refrigerator, washing machine or any other appliance for final manufacturing.

So, Training is the crux role to make the employees as a walking troops to get the desired outcome for the engineering related products. Trianing and development must be required prior to the task allocation and for various job role activities. Management is also widely associated with them for great success for the requisite departments.

There is some regural hierarchy which LG board members followed to make the team and individual department growth at rapid increase as given below:-

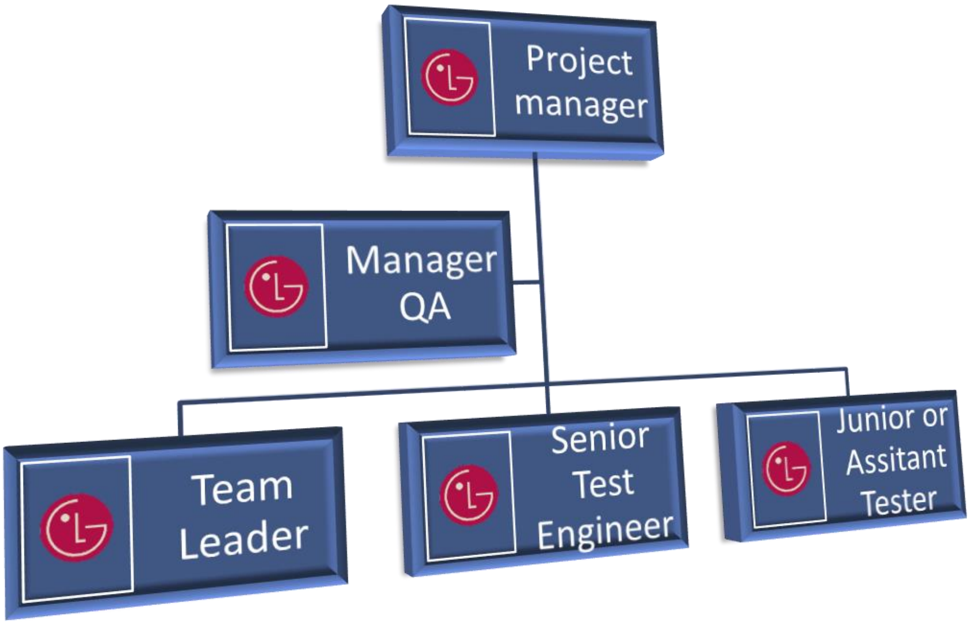


Fig.(a) *Hierarchy from trainee to the project manager role*

According to the specific department, the aforementioned hierarchical data is primarily taken into account from trainee or junior tester to project manager. In the Quality Assurance department, as in LG, the vision to start the product idea must come from board members with clear instructions before it is handed over to the Project Manager, the core development or brand-new product that is coming to market must be launched with an idea initially from the higher authorities. Additionally, the project manager must ensure that each individual electrical appliance will be manufactured flawlessly using the raw data that the authority provided. The configuration for other departments like Innovation, R&D, and Materials Development is also somewhat similar. Team leader associated with the link of the series with engineers, lab incharge officers and maintance engineers where the plans of current testing will be circulated and the task is majorily done in mutual way of solving the issues related to products which may occur during the development testing. Senior Engineer is responsible to perform the testing as well as the lab reports from DQA (Development Quality Assurance) to avail for better and on time results which the team leader is aiming for.

For further development, if in case the testing issue occurred or somewhat related issue which tends to halt or hamper the testing then Research and Development team must be called to rectify the problem related to do the testing from standards then after their successful removal of the issue then it is again continued with the same pace as required by the company's turnover. There is necessary tasks which is initiated from the project manager to make all the chain in such a way that all the processes from designing to final assembled product will be manufactured at the faster pace. Moreover, after completetion of these requisite products it will be gone for the development purpose to get the best approach of handling the product via development quality assurance.

TASK TO ACCOMPLISH (Washing Machine Division)

In outmost washing machine department, there is indeed requirement for quality check in the NABL (national accreditation board for testing and calibration laboratories) in order to get the complete analysis of the sample which had selected. There is two basic types of washing machine which is manufactured by LG in Noida plant given below: -

1. SEMI AUTOMATIC
2. FULLY AUTOMATIC

Additionally, these fundamental types had classifications of Armstrong, Sapiens, and High Efficiency Direct Derive (HEDD/VPlus) types. Model is well-known for being fully automatic, and the figure below illustrates a basic regular semi-automatic model.




SAPIENS *ARMSTRONG* *HEDD/VPlus* *Basic Model*

An appropriate flow chart is employed in order to choose the washing machine sapling whose test results are most promising. For pre-mass production samples, a specific sample size allocation exists. For 500 samples, for example, 4 samples will be chosen to check the performance characteristics, and similarly, for 1000 samples, 8 to 9 samples will be chosen for additional testing.

Keywords :- HEDD/VPLUS , Limestone Incrustation , Heat transfer Efficiency

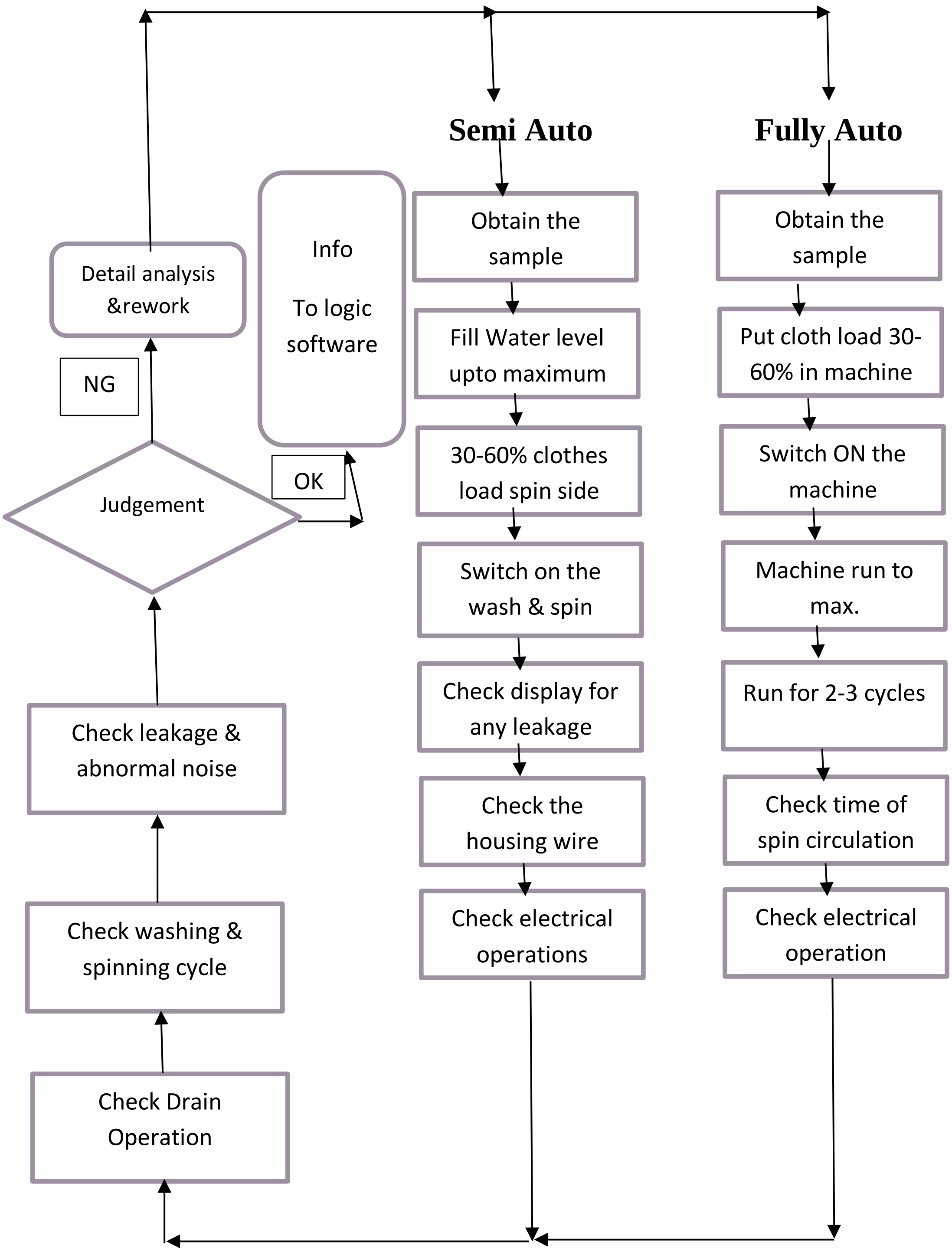


Fig.(b) *Flow chart illustrating the testing path from intial to final result*

TEST CYCLE

Sr. No.	Test Cycle
1	Continuous Running
2	30-60% clothes load
3	Wash & Spin both mode ON
4	Supply voltage as per cycle
5	Water level full

CHECK POINT

Sr. No.	Check Point
1	Power Consumption
2	Electrical Operation
3	Abnormal noise
4	Water Drain/ Drain Motor
5	Water Leakage
6	Function of spin & Wash timer
7	Buzzer/ Beep operation
8	Wash and spin motor operation
9	Water inlet operation
10	Aesthetic Check
11	PCB function
12	PCB Memory back-up (As per model)

Experimental Setup for research project on latest WMC model

The performance of the washing machine is affected when limestone builds up on the heater every two months following the required testing, which is a crucial role that was identified during the internship. This is the main loophole that was discovered during the internship, and it is where the build-up of limestone on the washer's heater causes problems with the machine's ability to rinse, use water efficiently, or use energy efficiently.

An experimental setup was created to address this problem and conquer the key findings that could diversify the primary problem to determine the desired performance of the washing machine for a high star rating of the product. High efficiency direct derive, also known as the HEDD model or Vplus, is the most recent model for this (Volume plus i.e. 10 Kg load capacity). In order to make a pertinent resolution to this problem, adequate research capabilities in terms of in-depth versions of testing and conditions were verified, and its limestone accumulation cause and time period were recorded in order to create an idea for the engineer or other qualified person in order to specifically address the issue of incrustation of limestone particles. This process adhered to the required standards set forth by the LG Korean-made standard, with the code LG(63)-F0-7000, which raises questions about the washing machine's actual capabilities.

Fig.(c) *Bone Dryier machine for removal of moisture contect in clothes for testing (LG INDIA)*

Its energy efficiency was evaluated in order to address the problem of limestone incrustation on the heater. Three examples of the fully automatic, top-loading HEDD washing machine model were chosen for this. Just at the beginning, when the model from the pre-mass production sample was removed for the experiment. Three samples in total were chosen at random from the pre-mass production stage and taken to the DQA (Development quality assurance) lab. For further assessment of the limestone, an energy test will be conducted to determine how much and where the limestone is accummulated. This test will be conducted in MEOST chambers under conditions of extremely high and low temperatures in order to construct the limestone accumualation provisionally. Three samples were continuously run for a month. After this process, the limestone visibility was clearly visible after one to two months, as shown in the figure. most effectively. Following the test conditions for energy testing under BEE (Buraue of energy efficiency) aids in instilling the behaviour of electricity consumption with and without limestone throughout the entire testing process.

In this instance, the HEDD model washing machine has a 10Kg load capacity, with the first 10Kg of the load being made up of bedsheets, towels, and pillowcases for the necessary test conditions. The load must be sent to a BONE DRYING apparatus where all the moisture in the load content of the clothiers was drastically removed in order to obtain the precise weight of a 10Kg load for a HEDD washing machine model after it has been exposed to the environment and has developed some moisture content. Bone dryer was taken into action until 30 minutes for particular cycle and immediate gets weighted down to the weighing machine in order to get exact load of 10Kg for the energy testing. After preparation of the load the energy tests were performed which is tethered with GTEMS machine apparatus to calculate the energy performance of the washing machine. Chemicals were used that took less than 15 days to accumulate the limestone by adding some hard chemicals that were easily made limestone on the washing machine heater in order to quickly make the hard water accumulation to test the machine sample. In order to quickly harden the water in the reverse osmosis tank, proper procedures are used.

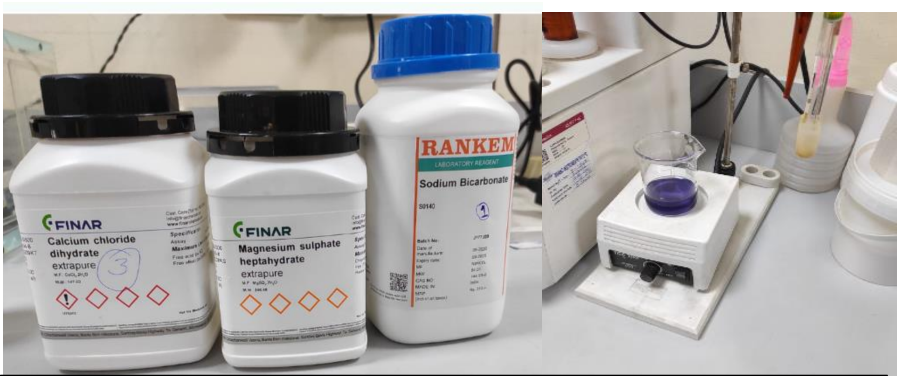


Fig.(d) *Chemicals were used from LG laboratory*

The chemicals used to harden the water in the RO tank so that it has a 50 ppm hardness in the water supply were far superior. The accumulation of limestone in the washing machine is determined by its hardness, which shows that more than 90% of the limestone is concentrated on the heater part and the remaining 6% was in the centre of the pulsator. Therefore, reducing the amount of limestone on heaters through appropriate research methodologies that were successfully implemented is the goal. The chemical calcium chloride dihydrate, magnesium sulphate heptahydrate and sodium bicarbonate were used in order to get the requires hardness of water prior to the testing for three samples of high efficiency direct derive or volume plus model of washing machine which is having capacity of 10kg load per sample i.e. for S1,S2 and S3.

Test gives proof of limestone incrustation's impact on heating effectiveness

The resulting limestone evidence is clearly shown in the figure to be more than enough to impair the washing machine's energy performance. Because of poor heat transfer from the heater to the surroundings caused by the accumulation of limestone on the heater and pulsator rotation during programme execution, there was also less thermal conductivity to transfer heat. It is considered that the incrustation of limestone may not satisfy customer needs, which is not a good thing.

Fig.(e) *Dismantled heater part of the HEDD washing machine with limestone accumulation*

The necessary heater component was then taken for XRD analysis, which revealed where and to what extent the limestone is accumulated. Additionally, heater coatings are to blame for the accumulation of limestone. This problem was discussed with the research and development team, and for action remedies, they took this into account. For further modification, the heater was put through additional testing, including the following: Rated capacity, coil resistance, cold insulation resistance, leakage current, voltage resistance, water proof insulation, NaCl solution (cyclic) test, terminal welding strength, assembling strength terminal and heater pipe, pull out strength, and thermofuse cut. These tests were necessary to taken into consideration so that the limestone incrustation will reduced in order to check the energy performance this heater is again put in assembly of the washing machine and tathered with the GTEMS (Global test equipment measuring system) machine which will calculate the energy performance charactericts of the particular samples.

***Fig.(f)** HEDD/Vplus samples of washing machine tethered with GTEMS apparatus*

Above mention requisite test plans for heater assembly is pretty much necessary to know that what exactly the type of heater coatings is incorporated having and what type of behaviour of the heater at its extreme conditions to check necessary behaviour prior to the overall assembly in the washing machine.

After proper investigation we can now make it viable for further testing according to the desired application in order to detect the issues like due to more limestone encrustation it will lead to decrease I thermal conductivity of heater with the reason of which it will get more energy or power consumption which may be not a useful. So, it's very obvious do these above mentioned tests before getting proper assembly to the washing machine models.

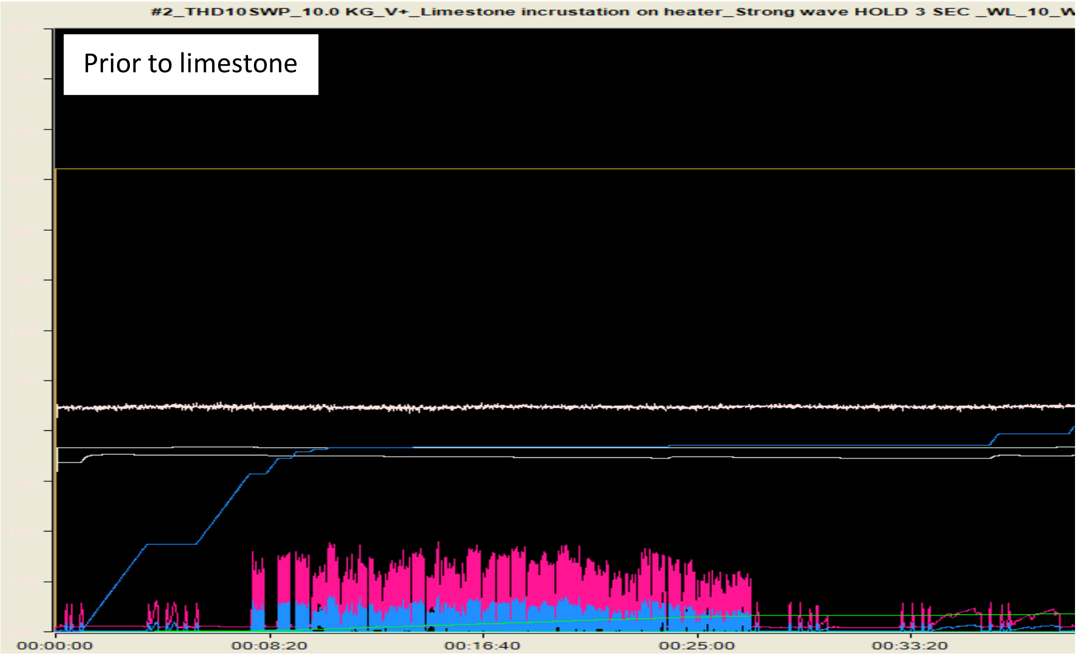
From Limestone which is caused by high turbulence , low thermal conductivity, and poor heat transfer due to high turbulence of the pulsator while rotataion of the pulsator during running machine . After clear analysis in the laboratory it is came to know that the limestone is there due to lack or poor coating content which provides the clear identification of the checmical equilibrium reaction with the heater which is given below:-

$$Ca^{2+} + 2\ HCO_3^{-} \rightarrow Ca^{2+} + CO_3^{2-} + CO_{2\ (dis)} + H_2O$$

The calcium carbinate which further leads to in two stage composition which is given below:-

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$$

Here the limestone energy performance characteristics can be depicted from the graphs which was calculated by the GTEMS apparatus effectively.



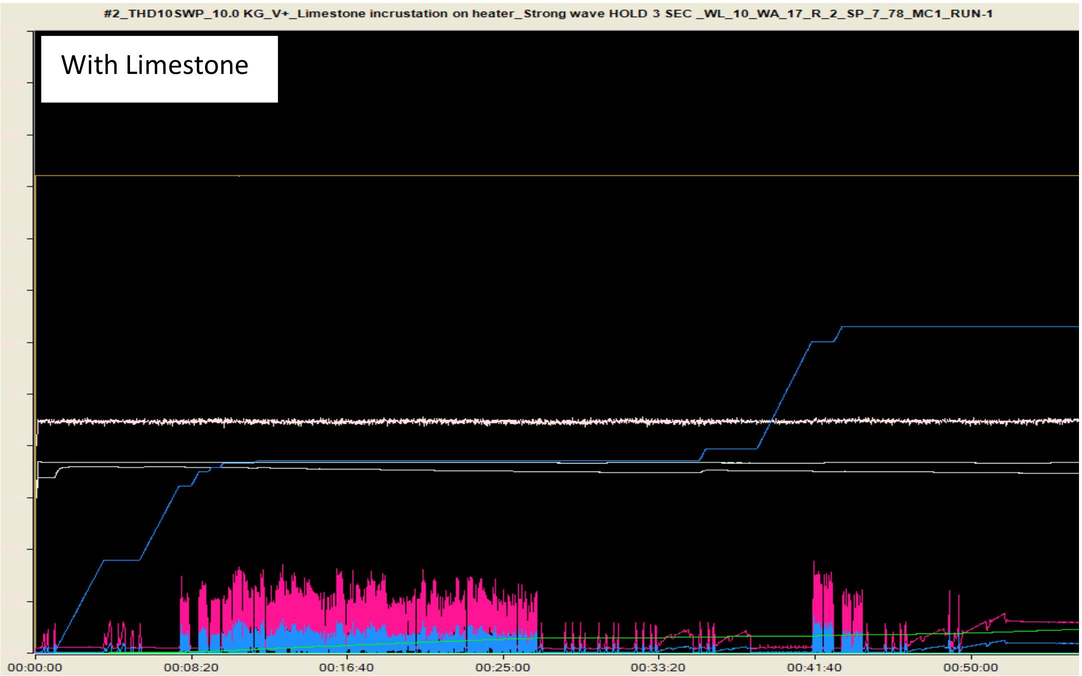


Fig. (g) *Above graphs depicts the performance characteristics for without and with limestone incrustation*

Hence, for star rating of the washing machine this kind of problem was sent for further modifications and the required condition must be satisfied which is given below:-

<u>Voluntary</u>

Test method: IEC 60456:2010

- Standard cotton 30ºC (without heater)
- Standard cotton 60ºC (with heater)

<u>Criteria for Star Rating Label (KWh/kg/cycle)</u>

 **Star Rating**	**Front loader**	**Top loader**
1 star	0.16<E<0.18	0.0171<E<=0.0185
2 star	0.14<=E0.16	0.0158<E<=0.0171
3 star	0.11<E<=0.14	0.0145<E<=0.0158
4 star	0.09<E<=0.11	0.0132<E<=0.0145
5 star	E<=0.09	E<=0.0132

<u>Minimum Requirement</u>

Requirement	**Front loader**	**Top loader**
Wash Efficiency	>=95%	>=85%
Rinse Efficiency	<=2.25%	<=2.25%
Spin (Water extraction)	<=75%	<=75%
Water consumption	<=9l/kg/cycle	<=23l/kg/cycle

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APPENDICES

Appendix A1

LIST OF PUBLICATIONS OUT OF THIS WORK

International Conference

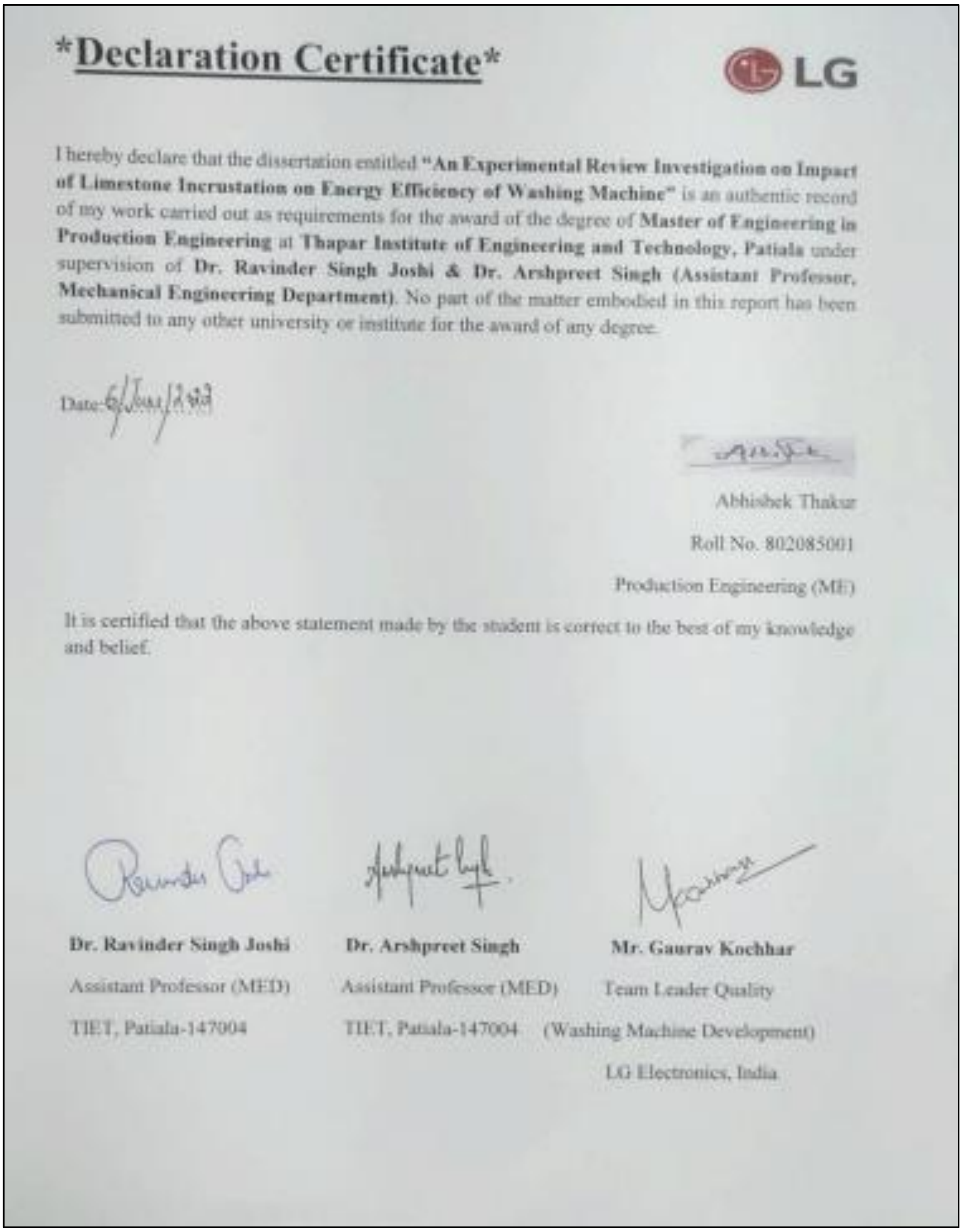
- Thakur, A., Joshi, R. S., & Singh, A. (2021). “A brief review on mechanical properties of Al-MMCs fabricated by stir casting route & applications”. In ***E3S Web of Conferences*** **(Vol. 309)**. EDP Sciences.

International Journal

- Abhishek Thakur * , Pushpinder Kumar ** , Ravinder Singh Joshi *** , Arshpreet Singh *****“An Experimental Investigation for Material Characterization and Tribological properties of Titanium (Ti-64) alloy for Aerospace applications**”(Communicated in IEEE Journal)**

Appendix A2

INDUSTRIAL PROJECT COMPLETED IN LG INDIA LTD.



Declaration Certificate

LG

I hereby declare that the dissertation entitled **"An Experimental Review Investigation on Impact of Limestone Incrustation on Energy Efficiency of Washing Machine"** is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering in Production Engineering** at **Thapar Institute of Engineering and Technology, Patiala** under supervision of **Dr. Ravinder Singh Joshi & Dr. Arshpreet Singh (Assistant Professor, Mechanical Engineering Department)**. No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

Date- 6/June/2023

Abhishek Thakur

Roll No. 802085001

Production Engineering (ME)

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

Dr. Ravinder Singh Joshi	Dr. Arshpreet Singh	Mr. Gaurav Kochhar
Assistant Professor (MED)	Assistant Professor (MED)	Team Leader Quality
TIET, Patiala-147004	TIET, Patiala-147004	(Washing Machine Development)
		LG Electronics, India

Appendix A3

Brief Bio-data of Author

The author, **ABHISHEK THAKUR**, born on 02-01-1996 graduated in Mechanical Engineering from Dayanand Anglo Vedic Engineering University, Sarmastpur, Punjab (India) in the year of 2017. After successful completion of his B.TECH he joined an multi-national company name LEADER VALVES LTD. as a designation of Quality Assurance Engineer from year 2017 to 2020. In year 2020, he joined his Post-graduation study (M. TECH) in Mechanical engineering with specialisation in Production Engineering from Thapar Institute of Engineering & Technology, Patiala itself. Meanwhile of 1st year of course work he was selected in LG ELECTRONICS PVT. INDIA LTD. for project work, there he had successfully completed the project work under the H.O.D. of Quality Assurance department which is "An experimental investigation on limestone incrustation on energy efficiency of washing machine"

The author is engaged in the requisite company name LG ELECTRONICS INDIA LTD. as a Quality assurance engineer since 2021 till present. He has 2 research papers to his credit which have been published in international journal and international conference of repute.

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