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Hardness Analysis of Ti-6Al 2Sn 4Zr 6Mo using Vickers and Micro Vickers Indentation Tests.

Muhammad Irfan Khan[1,*], Abdul Shakoor[1], Riaz Muhammad[2], Muhammad Usman[3], Numan Khan[1]

[1] Department of Mechanical Engineering, University of Engineering and Technology Peshawar, Pakistan.

[2] Department of Mechanical Engineering, CECOS University of IT & Emerging Sciences Peshawar, Pakistan.

[3]Assistant Engineer (Corrosion), OGDCL, Pakistan

*Corresponding Author: email: irfan@cecos.edu.pk

Abstract

Titanium and its alloys over the past few decades are becoming the preferred choice over other materials in a lot of engineering applications. This trend is driven by the balanced set of mechanical properties that these alloys exhibit like a high resistance to corrosion, high specific strength to name a couple. New alloys of Titanium are produced which need to be studied from differect perspectives. In this work both Vickers and Micro Vickers indentation techniques were used to evaluate hardness of recently developed alloy Ti-6246. To check the response of the material for any piles-up or sinks-in at the indents, light microscopy images were taken. They are also presented in this work. Further the effects of the projected area, indentation depth and indentation load on hardness values are also presented graphically.It was found that the hardness values obtained through both the techniques were in close agreement with each other and also with those reported in literature for Berkovich indenter. Also light microscopy images are obtained which show no crack initiations or piles-up at the boundary of the indents.

Keywords: Micro Vickers Indentation; Hardness; Contact; Area; Penetration depth; Light Microscopy.

1 Introduction

The objective of engineering techniques is to get the durable outcome at the lowest cost. For this reason extensive research has been done in developing the methods for enhancing the properties of already existing materials and to produce new materials in form of composites and alloys that will best fit the cause. Titanium (Ti) is one such metal that has gained a lot of attention of the material engineers. In the last couple of decades Ti has gained great importance in engineering sciences and has attracted a lot of market demand for numerous engineering applications for two reasons, one Ti has excellent mechanical properties ranging from good formability to the ability to put up with extreme temperature conditions and from high specific strength to excellent corrosion resistance and the second reason is that unrelenting research work has been done on Ti to develop new alloys of it with even better mechanical properties to meet the requirements of critical performance related applications [1]. Ti and its alloys have a vast scope of industrial applications.

This scope of application spans over many sectors like marine, offshore oil and gas plants, chemical, automotive, biomedical, aerospace, defense and many more [1]. The high melting point of around 1675 ^{0}C of Ti puts it in the position of most favorite choice for application in turbine engines [2]. The high specific strength of titanium and its alloys make it the perfect choice for the aircraft industry. The use of titanium in different version of Boeing Aerospace Company's aircrafts was around 15 million pounds. Now it is estimated that 20% of the basic structural components of the new 787 dream liner are going to be made of titanium alloys. The cost of the extraction of raw material, processing, production and manufacturing of titanium alloys remain on the higher side, but the most favorable set of properties that it exhibits compensate for all that extra cost. As the result of the research in the field of alloys development of titanium recently a new alloy Ti-6Al 2Sn 4Zr 6Mo (Ti-6246) has been developed. Ti-6246 is seen as a replacement of Ti-6Al 4V (Ti-64) the work horse alloy of titanium. Ti-6246 has many advantages over Ti-64 for instance Ti-6246 can be heat treated to higher strength and produced in larger sections. Moreover the 6 % Molybdenum contents of Ti-6246 make it corrosion resistant in reducing environment, making it a better choice for offshore oil and gas applications [3].

As Ti-6246 is a relatively new alloy, therefore, its behavior and properties are studied at different levels. Therefore, in this work Vickers hardness technique is used to find the hardness of Ti-6246. As hardness relates to the property of a material to resists plastic deformation mainly because of penetration further it can also be attributed to the ability to oppose bending, abrasion, cutting and scratching [4]. Hence hardness becomes one of the very important mechanical properties to check for engineering applications. On the other hand Vickers hardness tests were developed by Smith and Sandland in 1925 in UK to overcome the shortcomings of the traditional Brinell hardness test[5].

There are two types of Vickers hardness test in practice. This classification is based upon the nature of the testing and its objectives. The two types are Macro and Micro Vickers indentation.

Since 1900 Brinell test has been widely used to calculate the hardness of various materials mainly as rolled, as cast and annealed metals. In these cases the alloys are inhomogeneous. A large indenter of 10mm diameter is used in Brinell hardness tests, this averages out the inhomogenieties to obtain bulk hardness values. In contrast the macro Vickers indenter creates a smaller impression therefore the inhomogenieties present in the material are not averaged out as well as the Brinell test [6].

Nonetheless it is found that with the increment in test load and the consequent increase in the indent size the macro Vickers indentation tests yields fairly consistent hardness numbers. Macro Vickers indentation can be successfully applied to heat treated steels and cold-rolled metals.

By comparison micro Vickers indentation are done at low loads. It is used to assess the hardness variation whether intentionally or unintentional induced. Micro Vickers indentation also proves to be precise tool to characterize segregation and banding [6]. This helps in indentifying constituents and characterization of microstructure gradients. In other words we can say that macro Vickers tests are used to find gross product average but if one is interested in hardness gradient of the material then micro Vickers is the option. Another distinguishing feature between the two technique is that macro Vickers are performed at shop floor to find the bulk average hardness while micro Vickers test are performed in laboratories [5].

In the proceeding lines the procedure followed in Vickers indentation test of Ti-6246 and the results obtained are presented and discussed. Further the effects of parameters like penetration depth, contact area and diagonal size on hardness number are presented graphically.

2 Material and Methodology

2.1 Material

The material used in this work is standard Ti-6246 alloy, obtained from Gfe-Metalle and Materialien GmbH situated in Nuremberg, Germany. 2× Vacuum arc remelting procedure was used in the production of the subject alloy. Forging process was used to decrease the diameter of the rod from 200mm to 50mm in the two phase field followed by air cooling, stress-relief annealing and stripping [7].

2.2 Methodology

In total four samples were prepared which were cut from a round bar of Ti-6246. Each sample had a diameter of 45 mm & thickness of 6mm. To remove the roughness introduced by the sectioning, grinding of finer and finer abrasives was applied in sequences. Grit sequence of 120, 240, 320, 400, 600 mesh was applied in steps for 3 to 6 minutes. Between each steps the specimen was rinsed to remove the previous grinding media. Polishing wheels of eight inch diameter and speed range of 200-600 rpm was used. To keep the heat generated and the metal entrapment between particles at minimum wet grinding was applied. The indentation tests performed along with the facilities are tabulated in Table 1.

The micro Vickers indentation tests were performed using HVS-1000 Digital Micro Vickers Hardness testing equipment. Experiments were carried out at five different loads. Hardness number and diagonal lengths were directly recorded from the equipment while projected area was calculated using the formula, $A = \frac{d^2}{2\sin(\alpha/2)}$, in this case α the included angle of the indenter tip, is 136 ± 0.5 therefore area is then calculated as , $A = \frac{d^2}{1.8544}$. 'd' represents the arithmetic mean of the diagonal. The contact depth is found using $h^2 = A/4tan^2(\alpha/2)$, putting $\alpha = 136^o$

we get, $h = \sqrt{A/24.5}$ [8].

Table1: Facilities Used for Tests

S.No	Experiment type	Facility used
1	Vickers indentation	PITMAEM, PCSIR, Lahore*
2	Micro Vickers Indentation	MRL, UoP**
*Pakistan Institute of Technology For Minerals and Advance Engineering Materials.		
**Material Research laboratory. Department of Physics University of Peshawar.		

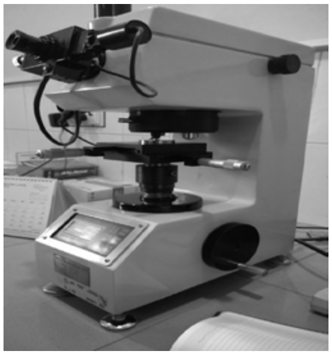

Figure 1: HVS-1000 Digital Micro Vickers Hardness

The Vickers tests were performed at PITMAEM of PCSIR laboratories complex Lahore. The indentation loads used were higher as compared to those used in micro Vickers indentation. Further light microscopy images of the indents were obtained to check for any piles-up or sink-in in the material.

3 Results and Discussion

The results obtained in micro Vickers indentation are tabulated in Table-2

Table 2: Micro Vickers Hardness Tests Results

	Loads(N)				
Vickers Hardness Values	**0.98**	**1.96**	**2.94**	**4.9**	**9.8**
1	465.69	460.52	288	344.23	297
2	465.69	378.22	333.75	286.53	386.13
3	460.52	367.1	311.19	291.63	393.19
4	288	341	309.31	323.34	355.56
5	344.23	369.12	292	263	391.21
6	297	342.54	297.33	282.92	395.72
Average value	367.78	359.76	311.40	296.35	392.61
St. Deviation	90.22	16.37	20.52	27.07	4.46

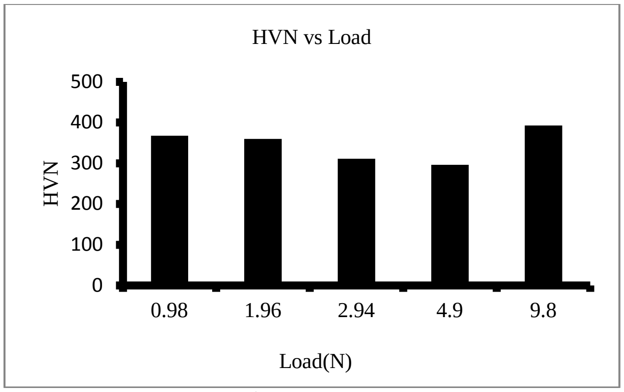

Figure 2: Results of Micro Vickers Indentation

To comprehend the data in a more effective way its plot is presented in Fig-2. It can be seen from Fig-2 that HVN number shows decrease in values as the load increases. Though at 9.8N load increase is recorded in the HVN number.

The relation of the load with the diagonal length is shown in the figure 3.

Variation in hardness values is observed, one reason to this situation is that as the load is increased it results in more penetration and an increase in contact depth and projected area is recorded. As discussed earlier hardness values depend on the contact depth and projected area therefore the results obtain here show dependence of hardness values on the indentation load [9].

Table 3: Indentation load and corresponding Diagonal Length.

Load (N)	**Average Diagonal Length (µm)**
0.98	22.78
1.96	32.12
2.94	42.43
4.9	54.18
9.8	68.54

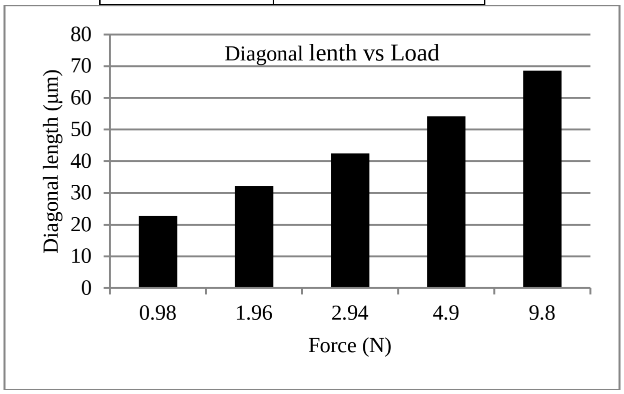

Figure 3: Effect of Indentation load on diagonal length

It can be seen in the figure above that with the increase in the applied indentation load the diagonal length of the indent increases. This is an obvious effect of increase in load. The diagonal length can be viewed in the light microscopy images provided later in this text.

As projected area is directly proportional to the square of the diagonal therefore as the diagonal length increases the projected area also increases. The effects of increasing load on projected area are similar to those on diagonal length and are presented in figure 4.

Table 4: Indentation load and projected area

Load (N)	Average Projected area (μm^2)
0.98	22.78
1.96	32.12
2.94	42.43
4.9	54.18
9.8	68.54

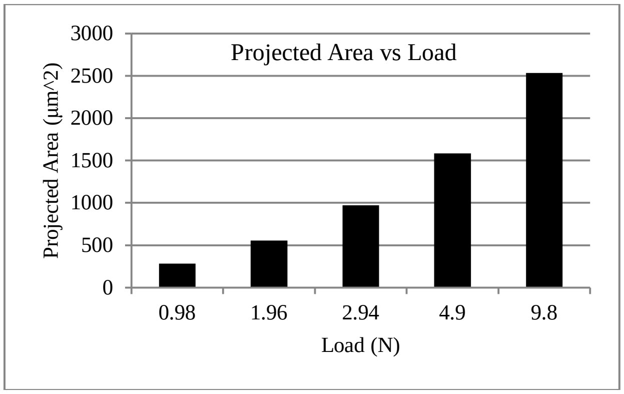

Figure 4: Effect of Indentation load on projected area

Contact depth is another important parameter to study for indentation tests. The penetration indenter made in Ti-6246 at different loads is presented in Fig 5. Again it can be seen that the contact depth increases as the indentation load increases. In other words indenter penetrates more at higher loads.

Table 5: Indentation load and Contact depth

Load (N)	Contact depth (µm)
0.98	3.38
1.96	4.76
2.94	6.29
4.9	8.04
9.8	10.17

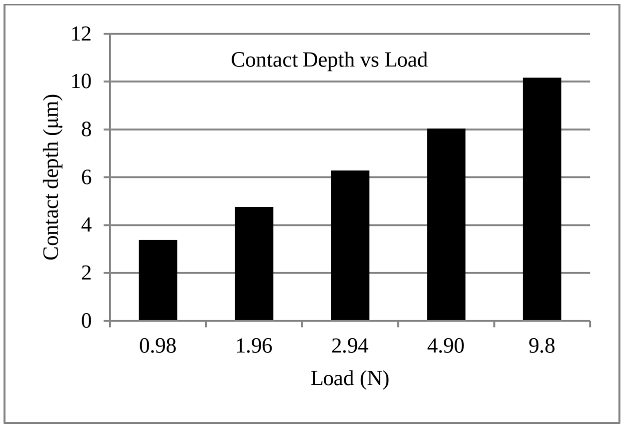

Figure 5: Effect of Indentation load on contact depth

Vickers indentation results are tabulated in Table 6 and the results are plotted in figure 6.

Table 6: Indentation load and Contact depth

Load (N)	HVN (avg)
49	342.74
196	342.11
294	346.69
490	344.82

The overall average of the micro Vickers indentation is HVN 292.92 while the overall average of Vickers indentation is found to be HVN 344. The difference is around 15% and this is due to the fact that micro Vickers indentation gives us more localized output while Vickers indentation gives us gross product averaged value as larger area is entrapped under the larger indenter tip.

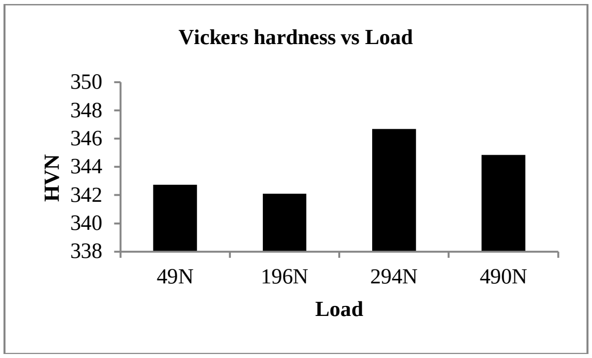

Figure 6: Vickers Hardness test results

Light microscopy images are obtained using Olympus PMG -3 coupled with Charged Coupled Device (CCD) with a DP-12 digital Camera shown in figure 7.


Figure 7: Olympus PGM-3

The purpose of these images was to check the response of Ti-6246 to indentation. To see whether any piles-up or sink-in are found along the indent boundaries.

Figure 8 shows the images of Vickers indentation while the light microscopy images of Micro Vickers indentation are presented in figure 9.

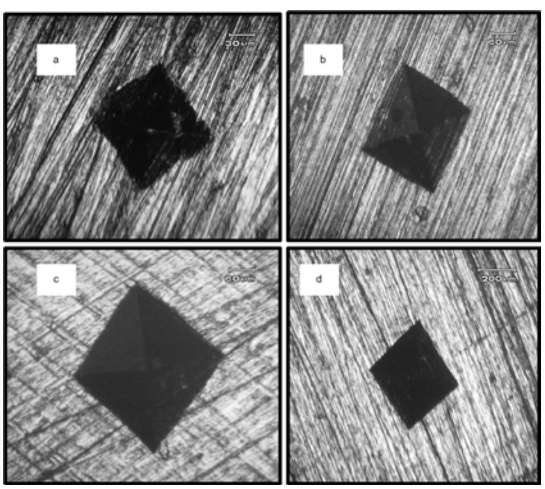

Figure 8: Light microscopy images for Vickers indentation (a) 49 N (b) 194 N (c) 294 N (d) 490 N

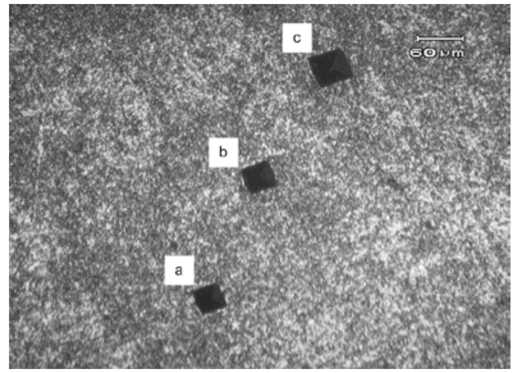

Figure 9: Light microscopy images for Micro Vickers indentation (a) 2.94 N (b) 4.9 N (c) 9.8 N

Examination of images of figure 9 shows no significant evidence of pile-ups.

4 Conclusion and Future Work

The main objective of this work was to analyze the hardness of Ti-6246 with both Vickers and micro Vickers indentation tests. Further with the help of light microscopy the response of the material to indentation was checked. It was concluded that the hardness values obtained for both types of test fall well within the range of hardness values reported for the subject alloy in literature for different types of indents. Moreover the hardness values obtained using Vickers indentation were slightly greater than those obtained for micro Vickers indentation because Vickers indents provide averaged hardness value. Further the diagonal length, projected area and contact depth all are related in direct proportion to indentation loads. If the load is increased all these parameters will experience as an increase.

Examination of some light microscopy images hint towards potential piles-up in the future with the help of Atomic Force Microscopy these piles-up will checked and quantified. Also, this data obtained can be used to find the fracture toughness of Ti-6246. In addition, nano indentation tests will be carried out to check its effectiveness in the characterization of the subject alloy.

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