EFFECT OF V ADDITION ON DRY SLIDING WEAR BEHAVIOUR OF TITANIUM MATRIX COMPOSITES

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The current study deals the dry tribological analysis of Titanium (Ti) reinforced with secondary particle such as vanadium (V). Powder Metallurgy (P/M) is used to manufactured the composite with varying the wt. % of the secondary particles such as 3 %, 6 % and 9 %. After successful fabrication of the composite, the composites were assessed the various properties such as physical and tribological behaviour. The density, hardness and tribological behaviour of the composites are assessed at room temperature condition. The results clearly evident that increasing the wt. % of secondary particles lead to decrease the specific wear rate and coefficient of friction. From the current analysis it clearly illustrates that Ti with the addition of 6 wt. % of vanadium composites significantly reduce the specific wear rate and coefficient of friction. Following to the extensive analysis such as scanning image analysis of the composite surface was assessed. It also shows that oxide layer is formed on 6 wt. % composite surface. It takes the composites into the passivation region.

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1. Introduction

For the past some decades, titanium is a fast growing material in many sectors such as automobile, medical industries etc. However, titanium is more active material and it is not easy combined with most ceramics. For this drawbacks, powder metallurgy is one of the most significant and easiest way to manufacture the components. There are many advantages are there, while making the component through powder metallurgy such as low cost, ease to fabricate and the wastage of powder is very minimal [1-3].

Mainly the properties of titanium matrix composites such as mechanical and tribological properties, are depends on fine grains of the composites. The fine grains are mainly depending on the nature of the powders and manufacturing technique. If essential post heat treatment will also have performed, in-order to attain the fine grains/microstructure.

Selection of secondary particles is also a crucial one in-order to attain a better composite property. In this research vanadium (V) is choose as a secondary particle. It has outstanding properties such as low hardness and high chemical affinity. Many researchers are undergone the research on titanium matrix composites via various manufacturing techniques such as liquid metallurgy, powder metallurgy and infiltration. However, many techniques are there, but powder metallurgy is very prominent technique in-order to manufacture the composites [4].

Shuying Li et al. (2021) studied the effect of titanium and its impact wear behaviour on ferrous alloy and the results directs that the steel wear conflict is mainly depends on hardness and toughness of the composites. Furthermore, it also reveals that 0.04 wt. % of Ti possessed better mechanical and wear properties than other composites.

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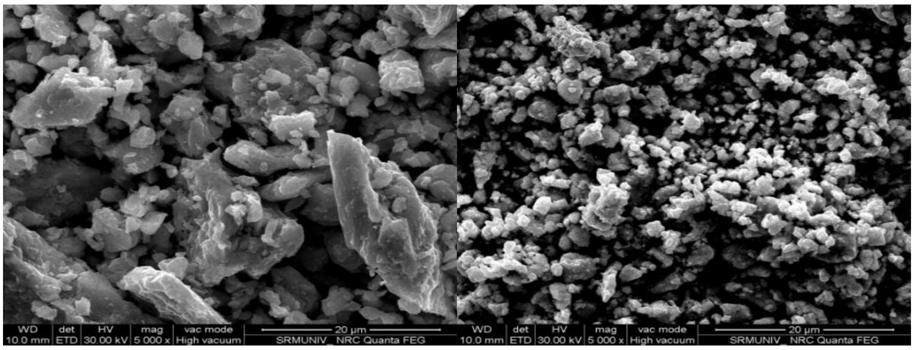
Zhang Jing et al. (2021) assesses the corrosion and wear behaviour of titanium alloy through surface treatment such as laser cladding and it illustrates that laser cladded titanium alloy provides better wear and corrosion properties than untreated alloy.

Few researchers are reported the dry sliding wear behaviour of titanium matrix composites and following to that titanium reinforced with vanadium particles through powder metallurgy are not studied earlier. Hence, the present research is focused on dry sliding wear behaviour of Ti-V composites fabricated through powder metallurgy. Initially, the as received powders were characterized using scanning electron microscope (SEM). After successful fabrication of the composite, the composites were assessed the various properties such as physical and tribological behaviour. The density, hardness and tribological behaviour of the composites are assessed at room temperature condition.

2. Materials and methods

2.1. Preparation of Ti-V composites

Titanium composites with three different weight fractions of vanadium (3, 6 and 9wt. %) were selected for this study. These precursors were purchased from sigma Aldrich, Germany. The as received titanium and vanadium powder scanning electron image are displayed in fig. 1(a-b) and it clearly reveals that it has irregular in nature and it is ease to bind easily without addition of any binders. In-order to manufacture the composites the pre-measured powders are mixed with proper ratio using mechanical alloying method for stipulated time period. The mechanical alloying was performed at a constant speed for the stipulated time period. Afterwards, the mixed powder was compacted as a green compact using compression testing machine. Careful attention was taken place for ejection of green compacts and immediately it was heat treated for the temperature of 900°*C for a* stipulated time period. After completion of this process, the compacts were undergone density measurement using water loss method and also the microhardness of the composites were also evaluated.



(a) *(b)*

Fig. 1. SEM image of as received powders
(a) Titanium; (b) Vanadium.

2.2. Microstructural analysis

After sintering, scanning electron microscope image is essential in-order to assessed the secondary phase distribution in matrix medium and it displays in fig. 2 (a). Presence of vanadium in the matrix medium is clearly visualized in the SEM image and the quantitative analysis is also one of the essential factor to assessed the quality of the manufactured samples and it displays in fig. 2 (b). It clearly displays the intensity variations mode of Ti and V.

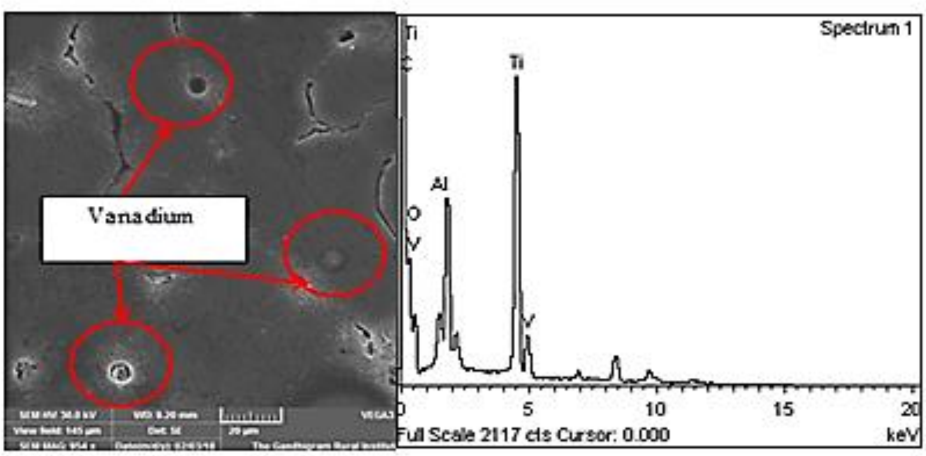


Fig. 2. SEM micrograph of a) sintered Ti-6V composites(b) corresponding EDAX spectrum.

2.2. Wear testing

In-order to assessed the tribological properties of the manufactured composites, these composites are undergone the wear experimentation. It was performed using pin on disc machine. In this experimentation, the composites were scratched against the high hardened steel. All the composites were manufactured as per the ASTM standard. The process parameters were selected before performing the experiment such as applied speed, sliding velocity and sliding distance. In this present research applied load and sliding velocity was varied keeping sliding distance as constant. After experimentation, the weight loss of the composites was measured manually using weighing balance and the weight loss is adapted into specific wear rate based on equation (1). Another one important response is coefficient of friction, it also calculated by using of frictional force data acquired from the experimentation and based on equation (2).

$$\text{Specific wear rate} = \text{Volume loss}/\ \text{Load} * \text{Sliding distance} \quad (1)$$

$$\text{Coefficient of friction} = \text{Frictional force}/\text{Applied load} \quad (2)$$

3. Results and discussion

3.1. Density and hardness measurements

Two types of density was calculated namely theoretical dnesity and actual density . Following to that the porosity of the composites were alos evaluated. All the composites having less than of 10 % of porosity and following to that the relative density of the composites are having more than 90 %. While incrasing the wt. % of the V, the relative density of the composites are also increasing and following to that the porosity of the composites is decreased.

However, using vickers, microhardness the hardness of the composites were assessed. The experimentation was performed under the load condition of 150 *kgf* load for 10 *s* using C scale. For an accurcy purpose, three different indentation was performed and the average value was taken. As per our experimentation, increasing the wt. % of V leads to increasing the hardness. The better hardness was showed for Ti-6V composites and it illustrates that 349 HV. After wards, it decreased because of the aggloremation of the V. The over all assessment of the density and hardness are listed in table 1.

Table 1. variation of density and hardness

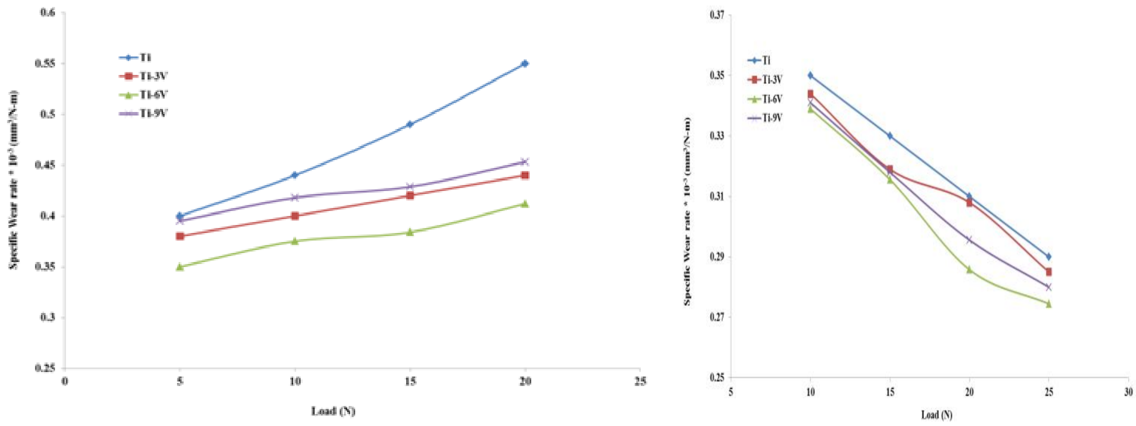
Wt. % of V Addition	Theoretical density(g/cm^3)	Actual density (g/cm^3)	Relative density (g/cm^3)	Porosity	Hardness (HV)
0	4.50	4.01	0.89	0.11	340
3	4.55	4.1	0.90	0.10	346
6	4.60	4.14	0.90	0.10	349
9	4.64	4.22	0.91	0.09	347

3.2. Wear test analysis for dry sliding condition
3.2.1. Specific wear rate

Fig. 3 (a & b) shows the specific wear rate of the composites with varying the parameters such as load and sliding velocity. The initial load was taken as 5 N and the final load was taken as 20 N as an incremental load of 5 N. Similarly, the sliding velocity was taken as 10 m/s and 25 m/s with the increment of 5 m/s. As per the load is concern, increasing the load will lead to increase the specific wear rate.

It was happening because of the contact to one another of composites and hardened steel. At initial, there is no V particles influencing are there, hence the metal contact is more, and the titanium having more active metal, it leads to high weight loss and parallel, to increment of specific wear rate. While increasing the V particles it acts as a passive layer on the composite surface. It acts as a passivation and leads to reduce the weight loss and parallel to specific wear rate. Eventually, Ti-6V shows better specific wear rate than other composites.

But according to the concern of sliding velocity, the reverse trend was observed. Increasing the sliding velocity leads to decrement of specific wear rate. It was happening because of no proper contact was happened between the surfaces of composites and hardened steels. Henceforth, it leads to decrease the specific wear rate and following to that Ti-6V displays low specific wear rate than the other composites. During sliding the oxide layer was formed on the titanium surface, though it has an active metal in the environment. The oxide layer act as a passivation to the metal and also to that the better bonding between the titanium and vanadium is also act as a serious concern of reduction of specific wear rate.



(a) *(b)*

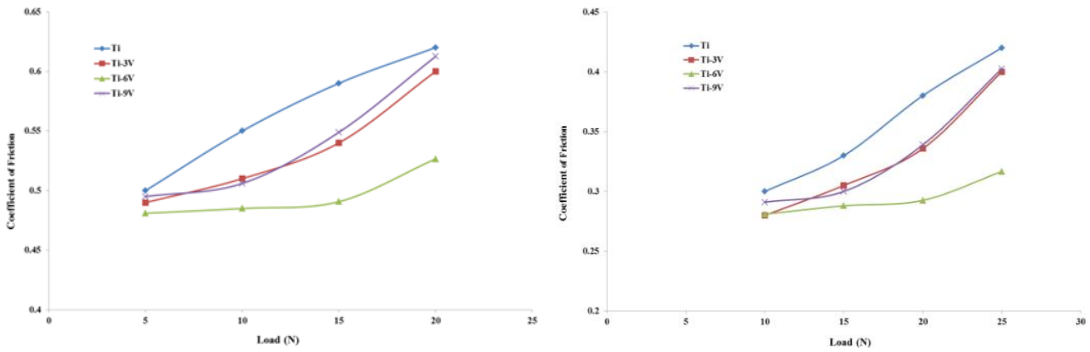
Fig. 3. Specific wear rate of Ti-V composites a) Load Vs SWR and b) SV Vs SWR.

3.2.2. Coefficient of friction

Fig. 4 (a & b) shows the coefficient of friction the composites with varying the parameters such as load and sliding velocity. The initial load was taken as 5 N and the final load was taken as 20 N as an incremental load of 5 N. Similarly, the sliding velocity was taken as 10 m/s and 25 m/s with the increment of 5 m/s. As per the load is concern, increasing the load will lead to increase the coefficient of friction.

It was happening because of the contact to one another of composites and hardened steel. At initial, there no V particles influencing are there, hence the metal contact is more, and the titanium having more active metal, it leads to produce high heat and parallel, to increment of coefficient of friction. While increasing the V particles it acts as a passive layer on the composite surface. It acts as a passivation and leads to reduce the heat and parallel to coefficient of friction. Eventually, Ti-6V shows better coefficient of friction than other composites.

But according to the concern of sliding velocity, the similar trend was also observed. Increasing the sliding velocity leads to increment of coefficient of friction. It was happening because of no proper contact was happened between the surfaces of composites and hardened steels. Henceforth, it leads to increase the coefficient of friction and following to that Ti-6V displays low coefficient of friction than the other composites. During sliding the oxide layer was formed on the titanium surface, though it is an active metal in the environment. The oxide layer act as a passivation to the metal and also to that the better bonding between the titanium and vanadium is also act as a serious concern of reduction of coefficient of friction.



(a) (b)

Fig. 4. Coefficient of friction of Ti-V composites a) Load Vs SWR and b) SV Vs SWR.

3.2.3. Worn surface morphology

Further, the analysis is to be enlarged in the direction of surface analysis to examine the what exact wear mechanism is taken place during experimentation. For this purpose, scanning electron surface analysis is essential. Fig. 5(a-d) shows the surface SEM image of various manufactured composites such as Ti, Ti-3V, Ti-6V and Ti-9V. From this image fig. 5(a) shows that many discontinuity material flow is observed along the sliding direction. It clearly reveals the severe plastic deformation will be encountered on the composite surface. On the other hand, many cracks were also viewed, it also leads to increase the plastic deformation. The results are clearly correlate with the above specific wear rate and coefficient of friction.

Fig. 5 (b) shows the titanium composites with the minimum vanadium reinforcement (3%). It illustrates that one secondary layer was observed on the image. It like coated to the entire surfaces. Eventually, it acts like a passivation to the surface. The secondary particle, have taken the charge and it moves the matrix in to passivation range. On the other hand, it clearly visualized that some of the debris particles are also sprinkled on the composite surface. It also reduces the plastic deformation of the matrix medium. Following to that a nominal wt. % of reinforcement such as 6 % are added in the matrix medium. It also clearly shows the drastic decrease of plastic deformation are quite often. Environment is also place a vital role during experimentation. While conducting the experimentation, the minimal amount of heat is generated between the composites and the counter surface. Due to the potential difference between the environment and composite surface, a huge amount of oxide was formed. In this concern, an oxide is transformed to an oxide layer and it act like a defensive to the surfaces. It reduces the plastic deformation of the composites. The results are clearly correlate with the above specific wear rate and coefficient of friction.

In contrast while adding little huge amount of secondary particles (9%) to the matrix medium, it again increases the specific wear rate. It was happening, because of the high amount of vanadium particle create an agglomeration in the matrix medium. Furthermore, the same lead was observed to the 3 % composites. Many cracks were also viewed; it also leads to increase the plastic deformation. The results are clearly correlate with the above specific wear rate and coefficient of friction.

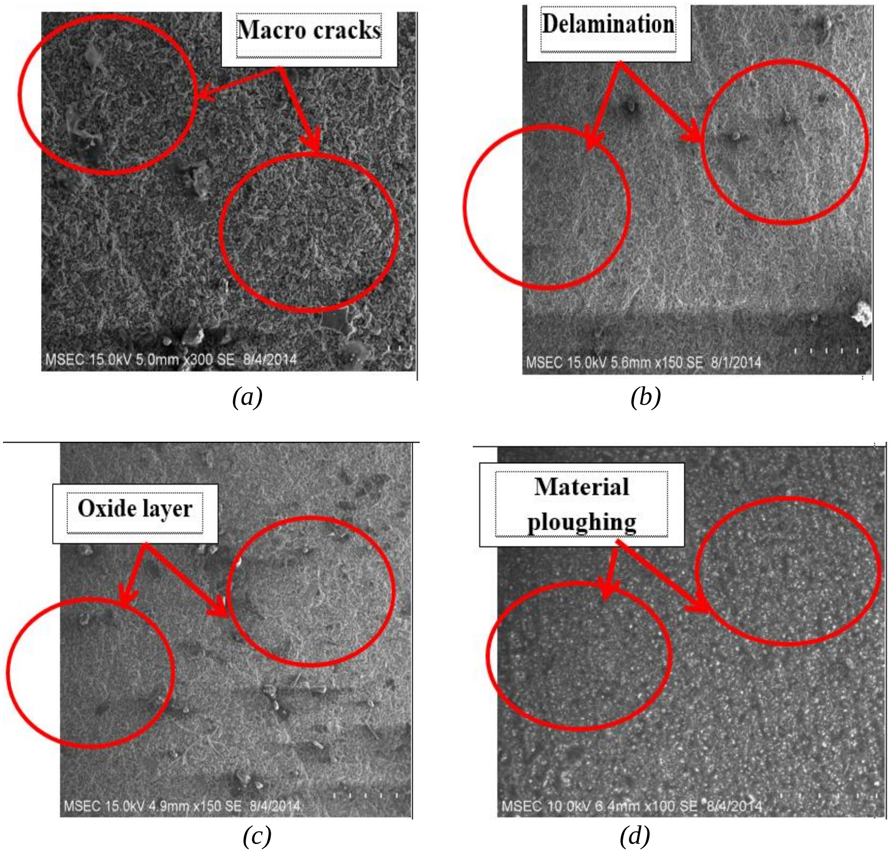


Fig.5.(a-d) SEM image of composite surfaces
a) Ti, b) Ti- 3 wt. % V, c) Ti- 6wt. % V and d) Ti- 9 wt. % V

5. Conclusions

From the current study, successfully the titanium composites were fabricated with the reinforcement of vanadium at various wt. % such as 3 %, 6% and 9 %. From the careful observation, Ti-6V possessed the better hardness compare to other composites. Its having the hardness range of 349 HV. Following to that the porosity of the composites is nominal level. It is the main reason for the increment of the properties.

While increasing the V particles it acts as a passive layer on the composite surface. It acts as a passivation and leads to reduce the specific wear rate and coefficient of friction. Eventually, Ti-6V shows better specific wear rate and coefficient of friction than other composites. According to the concern of sliding velocity, the similar trend was observed for coefficient of friction. Increasing the sliding velocity leads to increment of coefficient of friction. It was happening because of no proper contact was happened between the surfaces of composites and hardened steels. Henceforth, it leads to increase the coefficient of friction and following to that Ti-6V displays low coefficient of friction than the other composites.

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References

[1] Haiqiang Bai, Lisheng Zhong, Ling Kang, Jianbo Liu, Weijun Zhuang, Zhenlin Lv, Yunhua Xu, Journal of Alloys and Compounds **882**, 160645 (2021).

[2] Pushpinder Kumar, Ravinder Singh Joshi, Rohit Kumar Singla, wear **477**, 203774 (2021).

[3] D. Surrya Prakash, N. Dilip Raja, Materials Today: Proceedings **46**, 3712-3715 (2021).

[4] Jianbo Jin, Shengfeng Zhou, Yu Zhao, Qiang Zhang, Xiaojian Wang, Wei Li, Dongchu Chen, Lai-Chang Zhang, Optics & Laser Technology **134**, 106644 (2020).

[5] Shuying Li, Hao Yu, Yuan Lu, Jun Lu, Wenchao Wang, Shufeng Yang, Wear **474**, 203647 (2021).

[6] Zhang Jing, Qianqian Cao, Hu Jun, Ceramics International, (2021).

[7] Arvin Taghizadeh Tabrizi, Hossein Aghajani, Hasan Saghafian, Farhad Farhang Laleh, Tribology International **155**, 106772 (2021)

[8] Yulong Li, Peng Song, Wenqin Wang, Min Lei, Xuewen Li, Materials Characterization **170**, 110674 (2021).

[9] M.S. Abd-Elwahed, A.F. Ibrahim, M.M. Reda, Journal of Materials Research and Technology **9**(4), 8528-8534 (2020).

[10] Zeju Weng, Kaixuan Gu, Chen Cui, Huikun Cai, Xuanzhi Liu, Junjie Wang, Materials Characterization **165**, 110385 (2021).

[11] Yonghua Duan, Xinyu Wang, Dan Liu, Weizong Bao, Ping Li, Mingjun Peng, Ceramics International **46**, 16380-16387 (2020).

[12] Damian Janicki, Surface and Coatings Technology, 406, 126634 (2021).

[13] Azeez Lawan Rominiyi, Mxolisi Brendon Shongwe, Enoch Nifise Ogunmuyiwa, Bukola Joseph Babalola, Paballo Fortinate Lepele, Close, Peter Apata Olubambi, Materials Chemistry and Physics **240**, 122130 (2021).

[14] Anirban Naskar, Amit Choudhary, Wear, 462, 203475, (2020).

[15] Baochao Zheng, Wei Li, Xiaohui Tu, Fangwei Xu, Kan Liu, Suocheng Song, Ceramics International **46**, 13798-13806 (2020).