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Multicomponent laser coating developed on Ti-6Al-4V using *h*BN, Ni-coated-graphite, Ni and Ti powders for improving tribological performance

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Abstract

Multicomponent coating development is one of the present research trends in surface engineering applications. Favorable characteristics of multicomponent laser coatings are advantageous for prolonging tribological service life of wear parts. Low hardness and poor wear resistance of Ti-6Al-4V surface were enriched by developing laser coatings. In this present work, the pre-placed powder mixtures of *h*BN, Graphite, Nickel coated graphite, Nickel-Titanium were laser irradiated to form multicomponent coatings. The physical characterizations of the coatings were done under SEM, EDS and HR XRD analysis. Dry-sliding-wear performance was tested and significantly low coefficient of friction (0.15)was noted on the laser coated samples.

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*Keywords:*Multicomponent, tribological, laser coating, Ti-6Al-4V, low friction

1. Introduction

Titanium is the ninth most abundant element and having a significant role in modern development. Among the different grades of titanium alloys, α-Ti alloys do not exhibit ductile-to-brittle transition temperature[1]. In sub-zero to moderately elevated temperature these materials remain quite high structural properties enabling strength against

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fatigue failure and creep. The alpha-beta alloys of Ti include Ti-6Al-4V, which accounts for approximately 60 wt. % of the titanium used in today's industries for its unique properties mainly formability and strength. Some noteworthy characteristics[2] of titanium and its alloys are nonmagnetic and less heat conductive, sub-zero to moderately elevated working temperature, forgeable under standard techniques, cast able (investment casting method is preferred), process able using PM methods, joinable (using fusion welding, brazing and diffusion bonding),inert to most organic chemicals, bio-compatibility, excellent corrosion resistance with high specific strength, etc.

Such properties are very useful in aerospace and space shuttle applications which work in cryogenic to moderately elevated temperature. Thus, titanium alloys are used extensively in aerospace for both airframe and engine components[3]. In aircraft, titanium alloys are used to make highly loaded structural components such as bulkheads and landing gears, the engine fans, the low-pressure compressor. And approximately two third of the high-pressure compressor are made from titanium alloys. Ti alloys also make the firewalls, exhaust ducts, hydraulic tubing, and armor plating. Titanium alloys are more widely used in high-performance military aircraft. Approximately 42% of the structural weight of the new F-22 fighter aircraft is made by Ti alloys. The excellent corrosion resistance of titanium makes it a potential metal in the chemical, food processing, and petroleum industries. The typical applications include pipe, reaction vessels, heat exchangers, filters, and valves. In naval applications, titanium is used for ship propeller shafts and service water systems. Titanium is used to make rotors for pulp and paper industries. A growing use of titanium is in medical applications due to biocompatibility with the human body. The lower elastic modulus of titanium closely matches with the properties of human bone, which helps in cell growth and less bone degradation over long periods. Surgical implements such as hip balls, sockets, heart valves, dental implants, etc. are some common usage of Ti alloys. Ti alloys are used in fabricating many sports goods, including golf club heads, tennis rackets, racing bicycle frames, skis, scuba gas cylinders, and lacrosse sticks.

Inferior wear and hardness properties of Ti-6Al-4V restrict further crucial applications like fabrication of lightweight vehicle parts. Research works were carried out and are still going on the development of surface properties of the engineering components made of Ti and its alloys. The WC reinforced bulk coatings are popular in industries for the hard facing of steel. A few research works were reported on cladding/hard facing of Ti or Ti alloys using the WC reinforced MMC. Guo et al. 2010[4] developed hard (up to 1300 HV), wear and corrosion resistant clad layer on pure Ti. Li et al. 2011[5] worked with Ni-coated WC and developed Al_3Ti+TiB_2/ (Ni coated WC) +Al_2O_3/ nano-Y_2O_3 clad layer of hardness 1300-1450 HV. Selvan et al. 1999[6,7] worked with SiC and BN on Ti-6Al-4V and developed 0.6 mm thick hard clad layer. The thick clad with SiC shows microhardness up to 1500 - 2000 HV and with BN show hardness about 1500 - 1700HV. Meng et al. 2006[8] fabricated TiB_2 and TiC reinforced Ni matrix composite hard (1100 - 1400HV) and thick (about 1 mm) clad on Ti-6Al-4V substrate. Qin et al. 2007[9]developed 'Mo-N' based thin (about 0.02 mm) selective deposition on Ti-6Al-4V. The microhardness at the top of the deposition was about 2000HV. Li et al. 2013[10] worked on in-situ TiN and TiB particulate MMC clad on Ti-6Al-4V substrate. They developed clad layer about 0.75-1 mm thickness with microhardness ranging from 850 - 1250 HV. Haldar et al. 2014[11] developed multicomponent MMC coating, of thickness about 0.05 mm and microhardness about 2200 HV, on Ti-6Al-4V substrate.

In this present research work[12], experimental investigations were carried out on development of multicomponent, bulk laser coating deposition for tribological performance improvement of Ti-6Al-4V surfaces. In this concern, the *h*BN, Graphite, Nickel coated graphite, Nickel-Titanium preplaced powder mixture was laser irradiated on Ti-6Al-4V substrates. Mostly, TiN-TiC reinforced Ni-Ti, hard about 950HV, MMC coatings were developed which possess good tribological properties against dry-sliding wear performance. The coatings typically show significantly low coefficient of friction (0.15) against WC ball in 1400 m/min speed under 0.5kg loading conditions.

2. Experimental details

The Ti-6Al-4V substrates were used as base material. The preplaced powder combinations used on different samples are given in table 1. The powder materials were mixed and made homogeneous mixture and made like clay using 4% PVA solution. The powder clay then placed on the substrates using K-coater machine in order to obtain an uniform thickness of 200µm. The green coating samples were then placed into a muffle furnace for a period of about 20 minutes at a temperature of 150°C for baking.

Table 1. Preplaced powder combination on different substrates

sample group ID: T1110	sample group ID: T1111
*h*BN - 2wt.% Graphite - 2wt.% Ni+Ti (55:45 wt.%) - 96 wt.%	*h*BN - 2wt.% Ni-coated Graphite - 5wt.% Ni+Ti (55:45 wt.%) - 93 wt.%

Finally, the samples were irradiated using an Ytterbium Fibre Laser (YLR-2000) capable of delivering 2kW power having λ=1.06μm wavelength in continuous wave (CW)energy delivery with spot diameter of 3mm in argon shroud of pressure 1.5 bar. The cladding tracks were formed by varying lase irradiating scan speeds as in table 2. Sufficient time was allowed for the samples to cool down at room temperature before every subsequent operation.

Table 2. Laser cladding process parameters

fixed process parameters	pre-placed powder thickness: 200 µm; sticking agent: 4%PVA; Laser: CW energy supply, beam size: 3mm; beam inclination angle : 12^{o}; Argon flow pressure: 1.5 bar; used laser power =2000 W		
sample group ID	sample no.	scan speed (mm/min)	observation
T1110	Tr1	3500	track formed
	Tr2	3000	do
	Tr3	2000	good track formed
	Tr4	2000	do
	Tr5	2000	do
	Tr6	1800	do
	Tr7	1600	do
	Tr8	1400	do
	Tr9	1200	do
T1111	Tr1	2400	track formed
	Tr2	2200	good track formed
	Tr3	2000	do
	Tr4	1800	do
	Tr5	1600	do

The coatings formed on the samples are of uniform thickness and free from micro-cracks. The samples of the developed clad layers were cut by wire-electro-discharge machining process to get required shape and size of the samples for various tests. The samples were sliced and hot mounted by using non-conductive phenolic resin for exploring microstructure of the coatings. The hot mounted samples were polished like mirror surface by sequentially polishing of using SiC grit 320 mesh → SiC grit 600 mesh → SiC grit 1200 mesh → Diamond grit 1 µm → Al_2O_3 grit 0.5µm → Colloidal silica grit 60nm under Buehler Ecomet 300, Germany make grinder polisher. The samples were then etched carefully using Keller's reagent [1 ml conc. HF+5 ml conc. HNO_3+35 ml HCl+190 ml H_2O]and prepared for SEM analysis. Microstructural analysis was done on the cross-sections of the coating under SEM,Model: Carl *Zeiss* Supra-40. Different samples of dimensions 10×15×10 mm^3 were used for XRD (X-ray diffraction) analysis which was carried out by *X'PERT PRO, 3040/60, PANalytic* diffractometer with CuKα (λ=1.5418Å) radiation, so as to identify the various constituent compounds present in the coating.

Ball-on-disc type dry-sliding wear and friction were monitored while a WC ball was rubbing against the coating surfaces. Detail experimental conditions are: WC ball diameter: 5 mm, track diameter 5 mm, applied load 0.5 kg and 1 kg, run time 30 min., rotational speed 300 rpm.

3. Result and discussions

3.1. Microstructural analysis

The SEM studies were conducted on all the samples. Some coatings were well formed in the low to moderate laser scanning speeds in the range of studies. The samples formed with dense reinforcement are analysed for further experiments. The sample ID: T1110, sample no. Tr3, Tr4, Tr5, Tr6 and sample ID: T1111, sample no. Tr3, Tr4, Tr5 were selected for the same. The SEM images of coating topography raised underlaser irradiation scanning speed 1800 mm/min and 2000 W power on sample T1110 are shown in fig.1 (a) and (b).

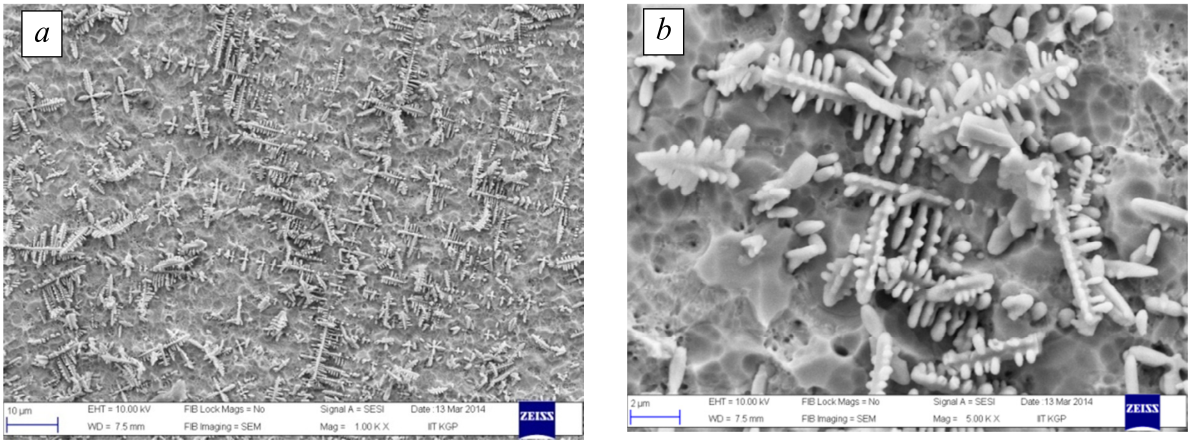


Fig. 1. The SEM image of the coating topography of sample ID: T1110, sample no. Tr4 formed under scanning speed of 1800 mm/min (a) at 1000 X magnification, and (b) at 5000 X magnification

In fig. 2 (a) and (b) are SEM images of coating topography raised under laser irradiation scanning speed 1600 mm/min and 2000 W power on T1111.To study the coatings elements, EDS analysis were conducted on various points of the coating topography achieved after deep etching of the mirror polished coating surfaces which are shown in fig.3 and fig.4.

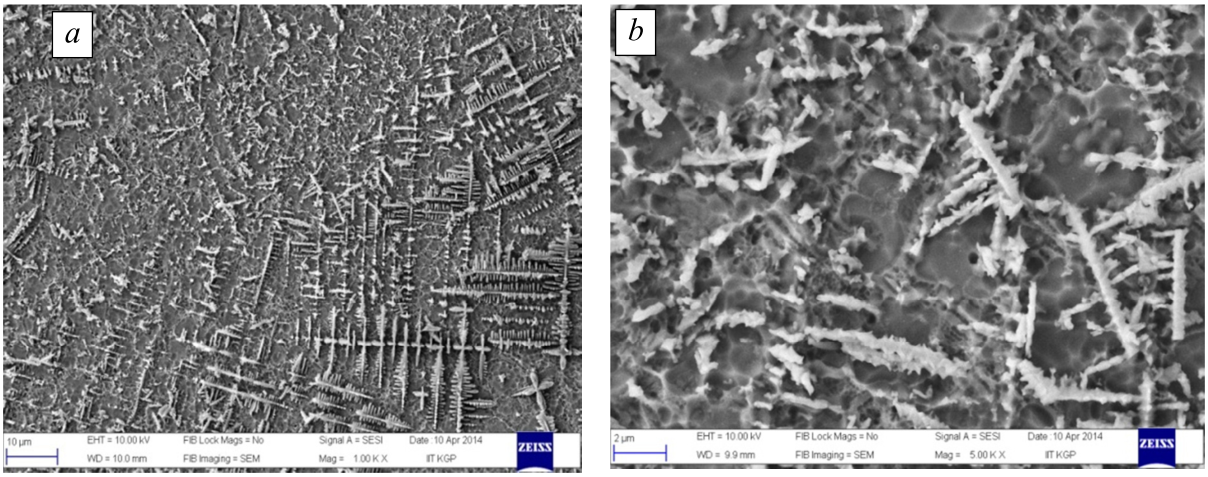


Fig. 2. The SEM image of the coating topography of sample ID: T1111, sample no. Tr4 formed under scanning speed of 1600 mm/min (a) at 1000 X magnification, and (b) at 5000 X magnification

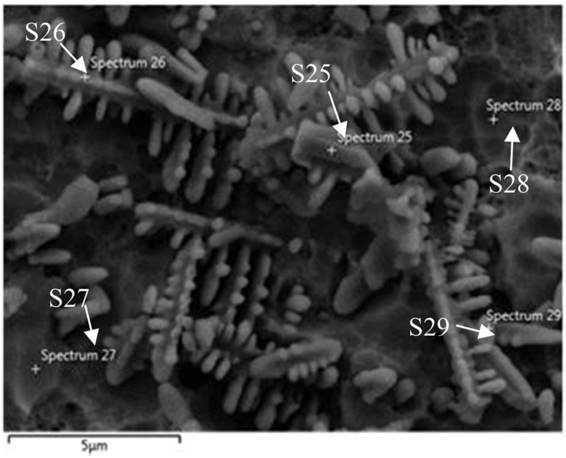


Fig. 3. Different points for elemental study of area in fig. 1(b)

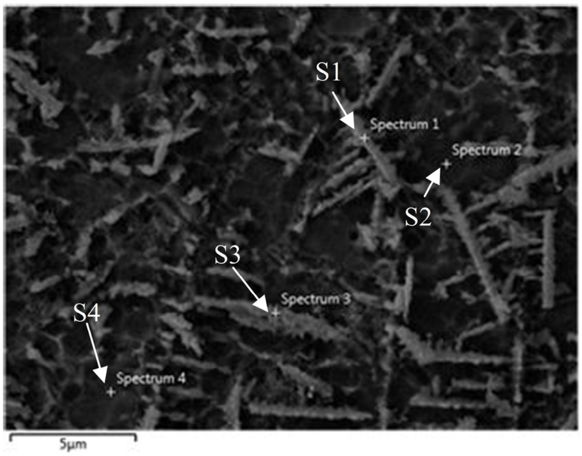


Fig. 4. Different points for elemental study of area in fig. 2(b)

Table. 3. Elemental details of coating reinforcements of fig.3

elements	**S25**	**S26**	**S27**	**S28**	**S29**
B	0.00	0.00	0.00	0.00	0.00
C	12.31	15.17	20.29	20.46	9.96
N	7.31	12.43	1.97	1.56	7.74
Al	0.25	0.61	4.55	4.51	0.95
Ti	79.91	71.16	61.44	65.17	79.78
V	0.00	0.00	2.95	2.21	1.58
Ni	0.21	0.63	8.80	6.09	0.00
Total:	100.00	100.00	100.00	100.00	100.00

Table. 4. Elemental details of coating reinforcements of fig.4

elements	**S1**	**S2**	**S3**	**S4**
B	0.00	0.00	0.00	0.00
C	3.24	16.32	3.65	18.92
N	7.59	0.00	8.21	0.50
Al	1.50	5.76	1.90	5.20
Ti	85.35	69.47	83.82	61.57
V	2.32	4.31	2.43	3.02
Ni	0.00	4.15	0.00	10.78
Total:	100.00	100.00	100.00	100.00

It is observed that, the microstructure showing a white phase as reinforcement in the dark matrix. From EDS results of the samples, it can be said that the dark particles contains considerable amount of Ni and Ti and the white dendritic structures contain considerable amount of Ti, C, and N.

3.2 XRD Analysis

The XRD analysis was done to study the various phases present in the coatings. The XRD profile of sample Tr4, sample ID: T1110 and sample Tr4 of sample ID: T1111 are given in fig.5 and fig.6 respectively.

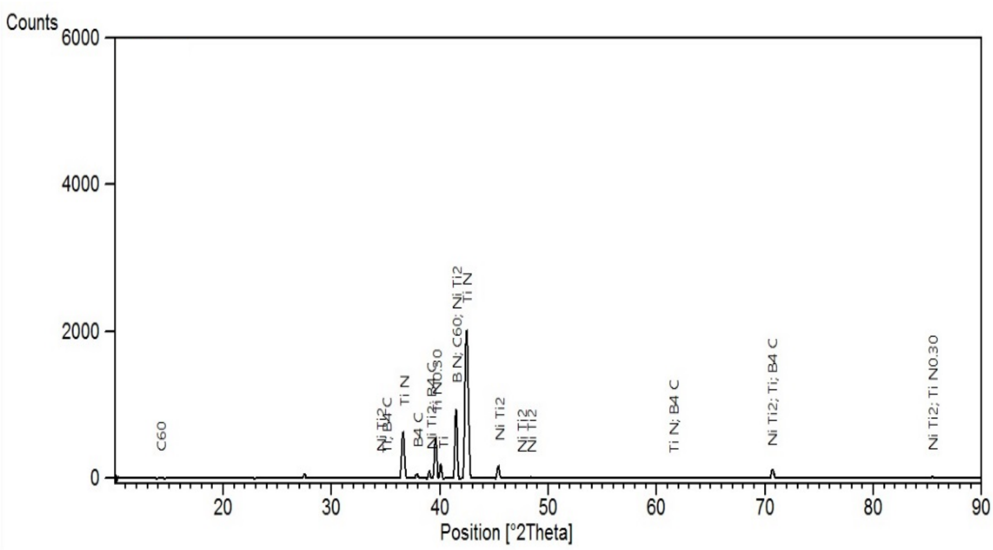


Fig. 5. The XRD profile of sample T3 of sample ID: T1110 (2000 mm/min)

The XRD profile of sample Tr3, sample ID: T1110 indicates that TiN, NiT_2, BN, $TiN_{0.30}$and B_4C are the main phases present in the coating.

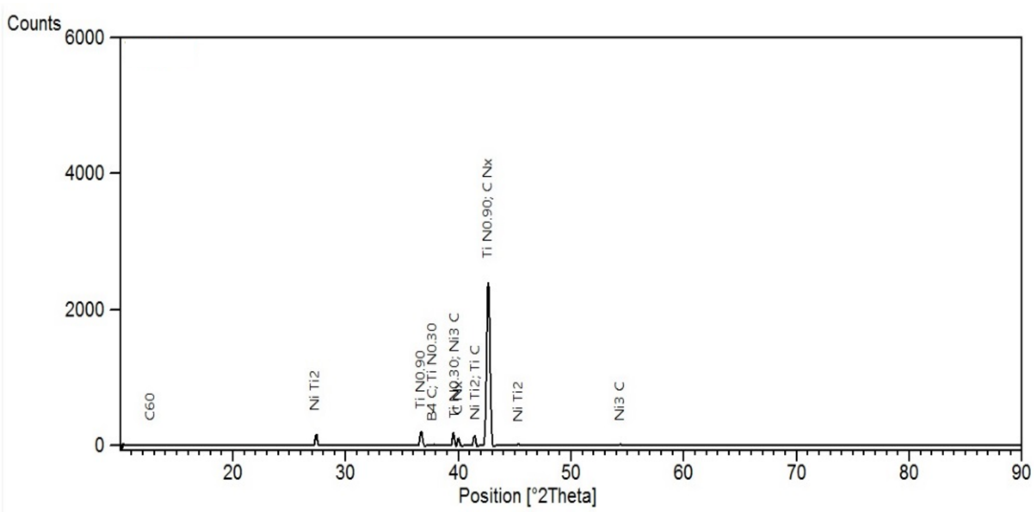


Fig. 6. The XRD profile of sample Ti3, sample ID:T1111 (1800 mm/min)

The XRD profile of sample Tr3, sample ID: T1111 indicates that $NiTi_2$, $TiN_{0.9}$, $TiN_{0.3}$,Ni_3C, and B_4C phases are present in the coating

3.3 Micro hardness study

The Vickers micro-hardness values for all coated samples were measured along the transverse cross-sections of the coatings. The average coating hardness throughout the coating cross-sections of various samples of sample ID: T1110 and sample ID: T1111 are shown in fig.7 and 8 respectively.

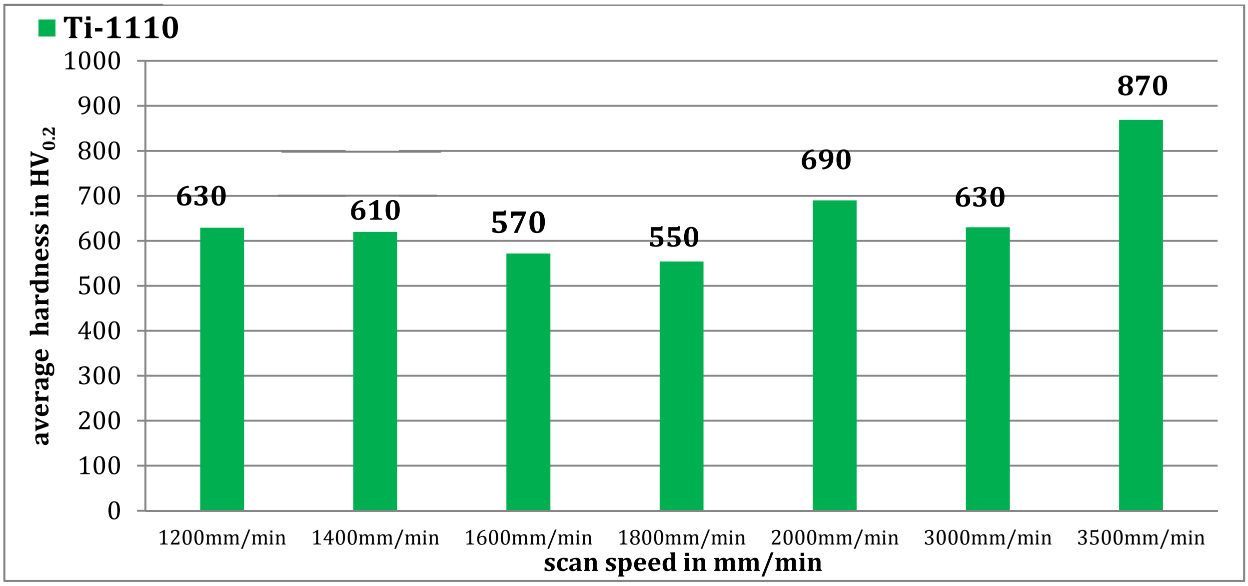


Fig 7. The average micro-hardness value along the cross sections of various samples of sample ID: T1110

In the sample ID: T1110, the maximum hardness 870 HV is achieved at scan speed of 3500 mm/min and dense dendritic reinforcement raised at scan speed of 2000 mm/min where the coating average microhardness is 690HV.

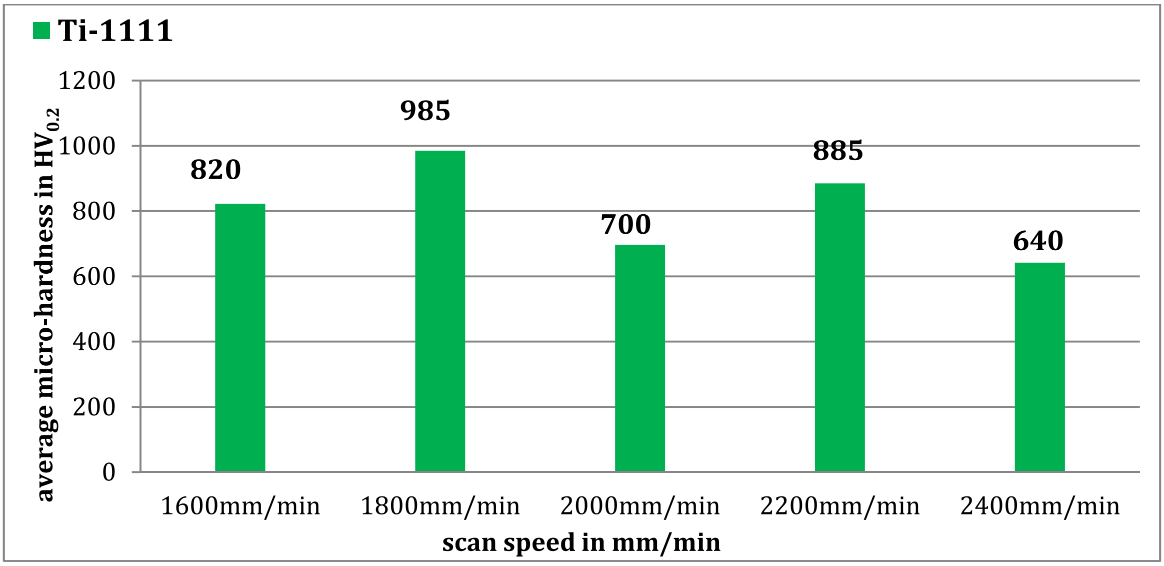


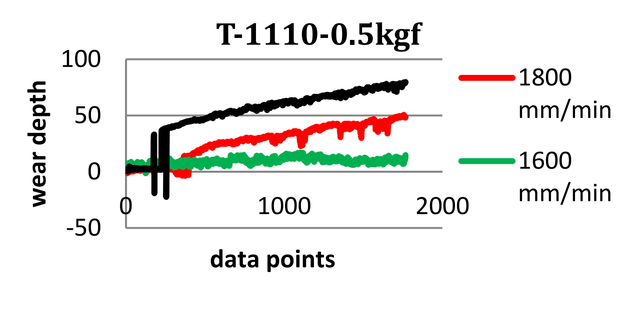
Fig 8. The average micro-hardness value along the cross-sections of various samples of sample ID: T1111

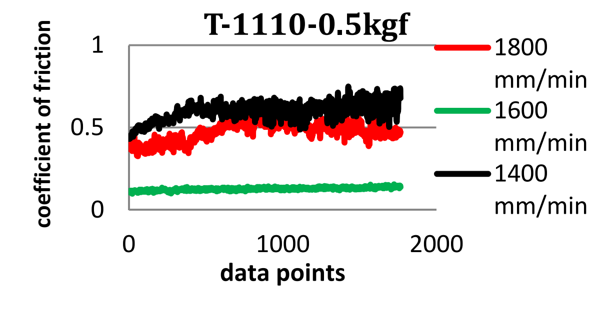
The samples of sample ID: T1111; the average microhardness is maximum 985HVat 1800 mm/min laser scan speed. The denser reinforcements were found in the coatings formed in 1800 mm/min laser scan speed.

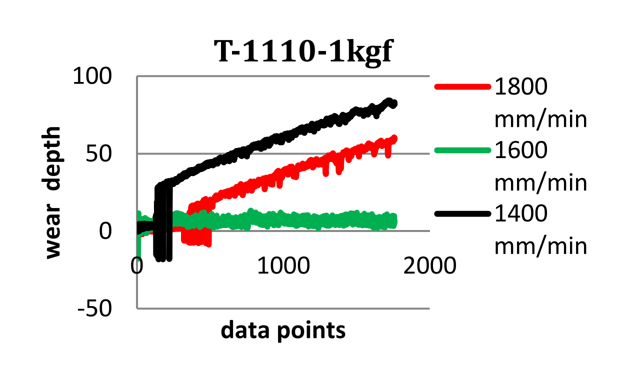
3.4 Wear tests

The dry-sliding wear tests were conducted on samples which were made using laser scan speed of 1400, 1600 and 1800 mm/min on the sample ID: T1110. The wear test conducted by varying loads on different coating samples.

Table 7. Wear characteristics of sample T4 of sample ID: T1110







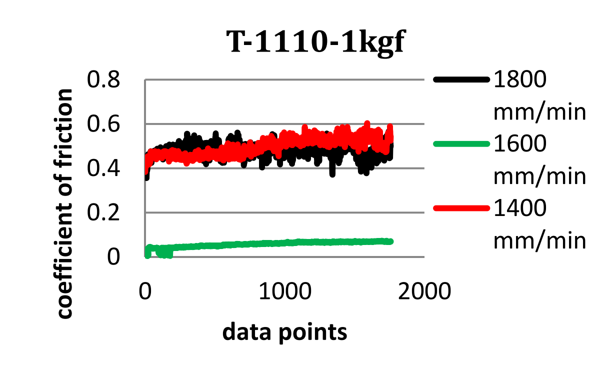
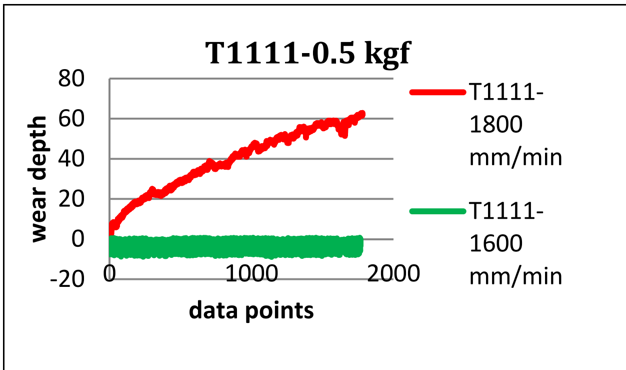
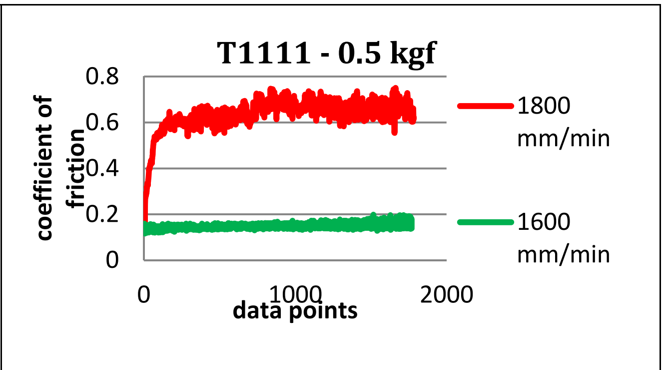
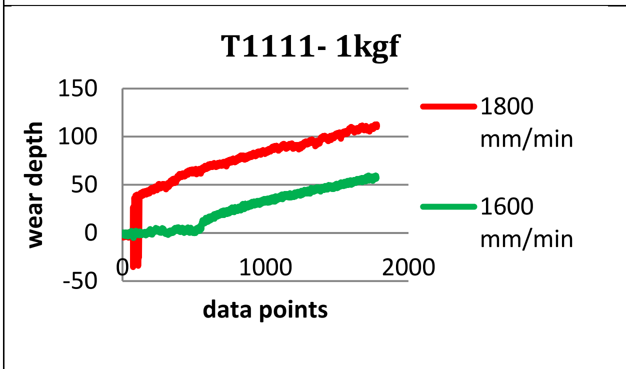
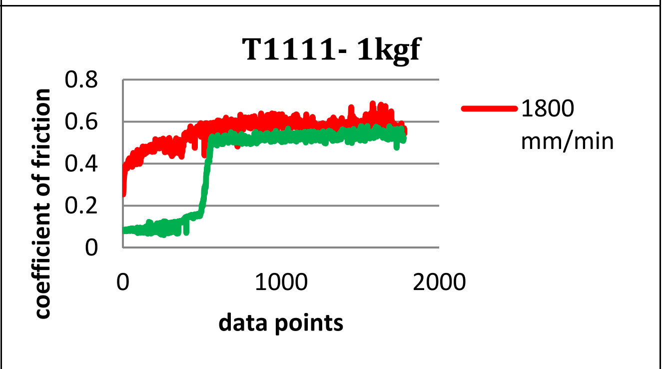


Table 8. Wear characteristics of samples of sample ID no. T1111









From the wear characteristics of the laser cladded samples, i.e., sample ID:T1110 and sample ID: T1111, it is clear that the coatings irradiated with scanning speed of 1600 mm/min show significantly low friction in low load.

4. Conclusions

Multicomponent, hard and wear resistant laser coatings were successfully developed on Ti-6Al-4V substrate by laser cladding techniques for tribological applications.

- The coatings were mainly reinforced with uniformly distributed TiC, TiB in NiTi matrix.
- The hardness of the coated samples were about 800HV which were more than double of the substrate materials.
- The wear performance of the coating was examined which show remarkable decrease in coefficient of friction about 0.15 at 0.5 kg loading conditions.
- There was no significant effect observed in coating performance while using Ni-coated graphite powders in the coating materials. It may due to rapid heating by laser source melt the Ni-coated graphite which react with the other coating elements.

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