Solid particle erosion wear of plasma sprayed NiTi alloy used for aerospace applications

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Abstract

Erosion is a severe wear phenomenon of compressor blade in aircraft where continuously solid dust particles strike the surface. So coating is essential to increase the life of the blade materials as well as the casing. In the aircraft engine, we have to keep focus on high wear resistance and high temperature resistant before choosing the materials to be coat. In this present investigation, Ni-Ti powder have been taken as coating materials due to its advanced properties like pseudoelasticity, high damping properties etc. Homogenized Ni-Ti powder has sprayed using atmospheric plasma spray process. Surface and interface morphology of the as-deposited material has been studied using scanning electron microscopy (SEM), the presence of the different phases revealed by using X-Ray diffractometry (XRD) and microhardness found out by vickers hardness tester. The as-deposited coating exposed to air borne particle erosion to investigate its wear properties by varying the erodent impact pressure and angle. Again the eroded surface has been studied by SEM for surface morphology investigation. It is found that the plasma spray Ni-Ti splats are well formed. NiTi and its derived intermetallics and oxide phases significantly present at the surface and interface that contributes the dense splat formation and higher hardness.

Keyword: Plasma spray, NiTi, Erosion, Wear, Microstructure

1. Introduction

The wear due to solid particle impingement on the surface of the aircraft compressor blade is a very common problem and a major reason behind the reduction of overall efficiency of the engine [1]–[3] and ultimately can become a cause of engine failure. So it is very essential to protect the surface of the blade from the failure due to solid particle erosion. Many researchers have been applied different types of coatings on the aircraft engine compressor blade such as TiN, CrN, ZrN, TiC [4]–[8] etc. We have introduced a new emerging material known as shape memory alloy or NITINOL (NiTi Naval Ordinance Laboratory). The nomenclature of the shape memory alloy was firstly done by Arne Olander [9] and the shape memory effect in NiTi was firstly recognised by William Buehler and Frederick Wang [10]. The main reason behind the selection of this material for coating on compressor blade is its special properties. The material consists of several properties like shape memory effect, pseudoelasticity, strength at fatigue load, high damping behaviour, high resistance to corrosion and wear, water erosion resistance, hardness at high temperature [11]–[15] etc. NiTi has a huge range of application such as aerospace industries, automotive industries, MEMS (Micro Eletro-Mechanical System) industries, biomedical industries etc due to its properties.

To coat this material, we have adopted one of the thermal spray coating i.e. atmospheric plasma spraying due to its coating flexibility, ability to coat intricate shapes, capacity to coat at open atmosphere and high adherent property of the coating. The principle of plasma spraying described as the injection of the powder particles into a direct current plasma jet, then the molten particles are directed towards the substrate where they solidify and form splat [16].

In this present piece of work, we have investigated the physical and mechanical properties of the plasma spayed Ni50Ti50 on mild steel substrate. The investigation is carried out using the microstructures as a tool. Again, the particle erosion wear test at different angles (30º, 45º and 90º) has been conducted on the coating surface. The surface morphology of both the weared and unweared sample have been investigated properly.

2. Materials and methods

2.1. Materials

An elemental mixture of Ni-50% and Ti-50% (at%) was mixed with turbula mixture for 6 hours to prepare a homogeneous mixture for plasma spraying. A mild steel plate of dimension 11.7 x 2.7 x 0.5 cm was taken as substrate material for coating. Before plasma spraying the substrate was sand blasted with Al_2O_3 grits to obtain a rough surface to increase the adhesion strength of the coating.

2.2. Methods

2.2.1. Thermal spraying

The coating is produced by the atmospheric plasma spray (APS) system (Metallization) at plasma spray division, Hindustan Aeronautics Limited (HAL), India. The substrate was heated at a temperature of 120º C before coating to create a proper heat transfer between substrate and coating and to obtain a well formed splat. Argon gas was used to generate plasma at a flow rate of 35 L/min. The distance between the plasma gun and the substrate was kept 120 mm, so that the particles will strike the substrate surface at a high velocity and there will be a low splashing. The coating parameters are given in the table 1,

Table.1. plasma spray parameters

Spray parameters	Unit
Substrate temperature	120º C
Powder feed rate	60 gm/min
Primary gas (Ar) flow rate	35 L/min
Carrier gas (Ar) flow rate	3.5 L/min
Secondary gas (H_2) flow rate	8 L/min
Stand-off distance	120 mm
Number of passes	7
Current	450 A
Voltage	30 V

2.2.2. Powder and coatings characterization

Both raw powders and coating were characterized by X-ray diffraction (XRD) (Brucker D8 Advance) using Co-Kα radiation (λ=1.79 Å) generated at 35 KV and 25 mA for phase analysis. The surface morphology of the coating surface and interface have been analysed by scanning electron microscope (SEM) (JEOL-6480 LV) at different magnification. Vickers hardness test was conducted by LECO micro hardness tester LM248AT. Surface roughness measurement has been carried out by stylus surface profilometer (Veeco dektak 150).

Solid particle erosion wear test has been conducted using ASTM G76 erosion test rig. the silica sand having hardness of 1420 ± 50 HV has been sprayed form a 1.5mm diameter nozzle at a pressure of 4 bar and flow rate of 3 gm/min from three different angle (45º, 60º and 90º).

3. Results and discussion

3.1. Powder characterization

The raw Ni and Ti powders has been characterized by both scanning electron microscope and X-ray diffraction method. The morphology of the powder shown in the figure 1(a) and 1(b). From the figure 1(a), it is shown that the nickel powders look like flakes and flowers shape. The EDS spectra confirms the purity of nickel powder given in the figure 1(a). Angular and non-uniform shape of the Titanium powders has been observed from the SEM micrograph given in the figure 1(b). The flowability may be affected by the irregular shape of the powders and it will be less when compared to spherical shape powders. The XRD analysis shows the presence of Ni and Ti phase in the corresponding powders (figure (c) and (d)). Different planes have been represented on the corresponding peaks.

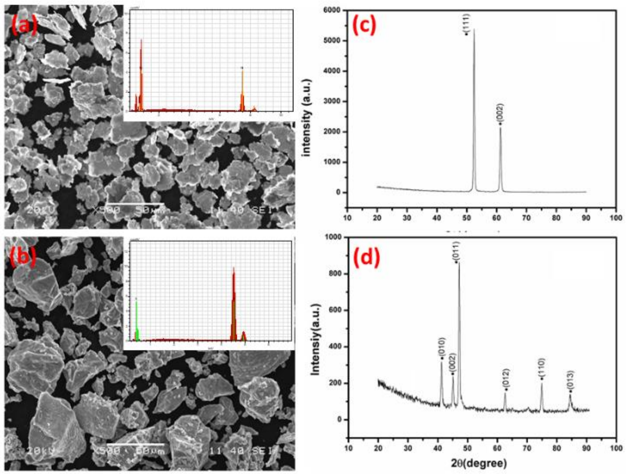

Fig.1. (a) and (b) SEM morphology with EDS spectra of Ni and Ti powders respectively, (c) and (d) XRD peaks of Ni and Ti powders respectively.

3.2. Coating characterization

3.2.1. SEM morphology

The SEM morphologies of plasma sprayed NiTi coating have been shown in the figure 2. The figure shows that there is very less amount of unmelted particles present on the coating surface. This indicates that there is proper plasma formation and a proper heat transfer between plasma and particles. The particles are properly melted and formed sheet like splats. The splats are overlapped on another splat. Though the splat formation is good but they are having fingers. These fingers are due to the vaporization of adsorbates and condensates under the splats [17]. To rescue from this effect and to get a disk shaped splat Fauchais et al [18] and Fukumoto et al [19] suggested to preheat the substrate over the so called transition temperature, because all the organic substances evaporates at this temperature. Research shows that [20], [21] if the spray angle is not orthogonal to the substrate the splats are elliptical and if the substrate is not preheated then lot of fingers will be there. But in our coating the fingers are very less and the splats are not completely elliptical, so it is obvious that our coating was done orthogonally and we have heated the substrate at 120º C as mentioned in the parameter table (table 1). The surface topography reveals that there are the microcracks present on the coating. These microcracks are the result of sudden cooling during the coating process. Due to these microcracks the corrosion rate will be more as the water will penetrate in the cracks, forms cavity and finally damages the substrate material. These microcracks can be avoided by controlling the cooling rate during coating. The EDS spectra of figure 2 represents the chemical composition of NiTi coating at different regions. In figure 2(a) the region given by composition '1' is the pure titanium area or titanium rich area. Here we can see that the titanium splat is well formed and melted completely. Fingers are less in this region. But at some portion of the periphery the splat is peeled off. The region behind this phenomenon disclose that it is due to surface tension. Another reason behind this is the improper heat transfer at the periphery. At the centre of the splat the heat accumulated is more but at as goes towards the periphery the heat is completely transferred. The splat under this splat was cooled and solidified first, so when the upper splat was cooled the heat transfer rate was more and it behaves as the coating is formed on the cold substrate. At the region '2' of the figure 2(a) there is some unmelted particles. But by EDS analysis we have seen that the area under region '2' belongs to the Ti_3Ni phase. This figure confirms the phase obtained by the XRD analysis. At figure 2(b) the region '1' indicates the titanium oxide phase. Titanium oxide is formed due to high temperature spraying. This oxide layer is very much advantageous to protect the surface from corrosion. The region '2' in the figure 2(b) shows the EDS spectra of nickel oxide confirmed by XRD analysis.

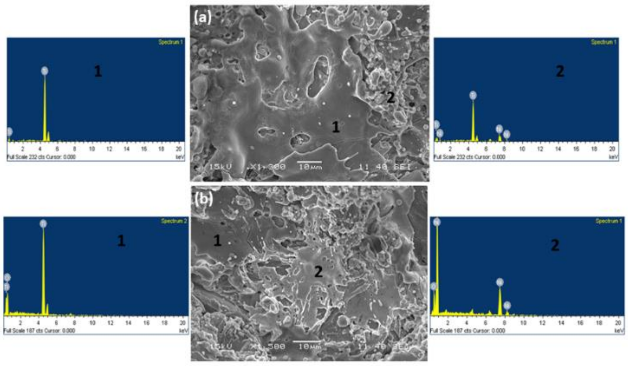

Fig.2. SEM morphology of plasma spray NiTi coating

The cross sectional morphology of plasma sprayed NITINOL coating is described by figure 3. It can be shown that the coating adhesion is good with the substrate material. The interfacial studies show that the dark colour region is the oxide phases confirmed by EDS spectra. The area under the elliptical region indicates the entrapment of one splat under another one. The coating is not uniformly distributed. The oxide region is more than the intermetallic region. This is due to the process i.e. atmospheric plasma spraying (APS). As the coating was done in open atmosphere the oxides are contaminated on the surface of the coating. From figure 3 it can be shown that the roughness of the coating is considerably high. The roughness measured by stylus profilometer was 9.5 µm. This is due to the sprayed powder particle size. If we reduce the particle size of the powder the coating roughness ultimately reduced and the bonding between the particles will be good enough. From the interfacial view the average thickness of the coating obtained as 45 µm. The thickness of the coating can be increased by increasing the number of passes.

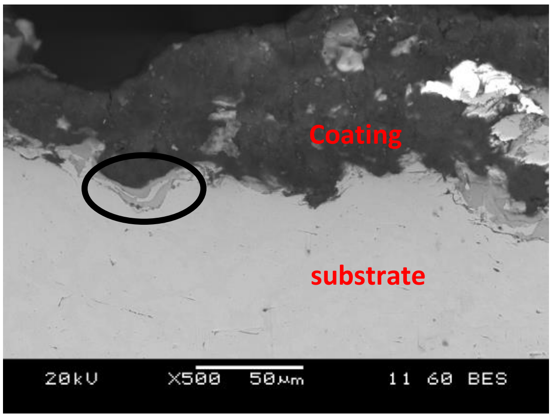

Fig.3. Interfacial view of plasma sprayed NiTi coating.

3.2.2. XRD analysis

Figure 4 represents the XRD analysis of the plasma sprayed NiTi coating. From the figure we can see that different phases are present in the NiTi plasma spray coating. These phases are TiO, NiO oxide phase, NiTi (both B2 and B19'), Ni_2Ti, Ti_3Ni intermetallic phases and pure Ni and Ti phase. Oxide phases are formed due to the atmospheric plasma spraying process. The coating in open atmosphere enhances the formation of oxide phases. NiTi-B2 phase austenitic phase is of cubic crystal structure. The NiTi-B2 phase are formed in the space group of Pm-3m and on the planes of (011) and (002). NiTi-B19' phase has been formed at P1-m1 space group and (111) plane. This phase is the martensitic phase having a monoclinic crystal structure. Formation of NiTi-B19' phase is less as compared to NiTi-B2 phase. As there is a minute amount of Ni_4Ti_3 phase present in the coating so peaks have not that much intensity to consider this phase. Due to absent of Ni_4Ti_3 phase the R-phase which is of rhombohedral crystal structure is absent. The figure indicates that the formation of pure Ni and Ti was occurred. This is due to the feed stock powder preparation. As we have supplied elemental mixture of Ni and Ti as the feed stock material. The density of both the powders are different. So during spraying the powder having more weight comes and sprayed on the splat formed by the lighter powder. Ni_2Ti and Ti_3Ni phases having contribution to the hardness and wear resistance of the coating. These intermetallics formation is due to the diffusion of Ni and Ti powders. All phases having contribution to enhance the properties of the NiTi coating.

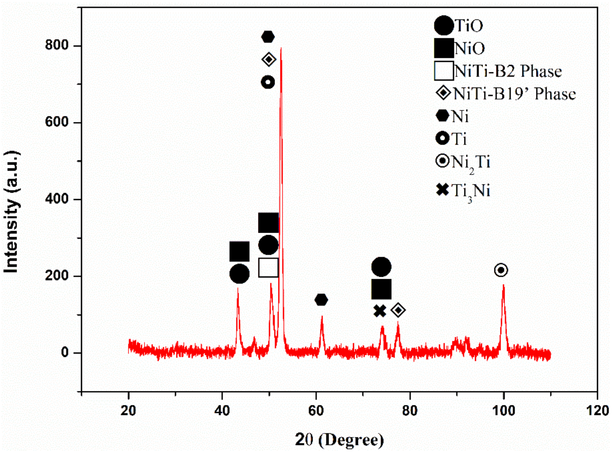

Fig.4. XRD analysis of plasma sprayed NiTi coating

3.2.3. SEM morphology of eroded surface

Figure 5 represents the SEM morphology of the eroded surface. In the three figures i.e. figure 5(a), (b) and (c) the morphology shows the three different types of crater formation of the sample impinged at three different angles i.e. 30º, 45º and 90º respectively. The formation of the crater in 30º impinged surface having most elliptical shape (figure 5(a)). The wear mechanism here is the wear due to abrasion between the silica and the coating surface. The silica particle slides over the coating surface and damage the coating by applying shear force on the surface. The crater of the eroded surface impinged at 45º is less elliptical than 30º impinged crater (figure 5 (b)). Because in 45º impinged surface the two components (tangential and perpendicular) of the force are active equally. So when the silica particle strikes the surface of the coating from the 45º angle the depth of the crater is more than the depth of the crater of the 30º impinged angle. But the length of the crater of 45º angle is less than the 30º impinged angle. So here the combination of abrasion and plastic deformation mechanism has a big hand in damaging the surface. The crater formation in 90º impinged angle is circular (figure 5(c)). Here the wear mechanism is only plastic deformation. The perpendicular component of the force having the dominant effect here. The wear resistance of the material has the direct dependency on the hardness of the material. The hardness of our coating is 760 HV, which is good for wear resistance. It can be shown from the figure that the erosion occurred more in lower angles and less in higher angle, which indicates the ductile behaviour of the coating.

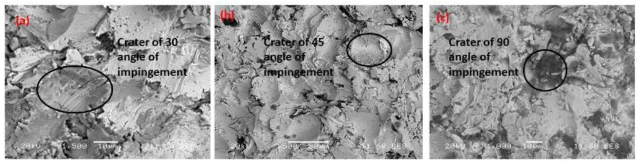

Fig.5. SEM morphology of weared coating sample at different impingement angle (a) 30º, (b) 45º and (c) 90º

Conclusion

The coating of Ni50Ti50 successfully applied on the mild steel substrate by atmospheric plasma spraying method. Different intermetallic have been formed after coating confirmed by XRD analysis. Due to oxide phases the formation of more intermetallic has been restricted. From the surface topography the confirmation of splat formation was done. The reason behind the low finger formation as the substrate preheating. From interfacial view the coating thickness and adhesiveness can be observed. The layer wise splat formation is confirmed from interface morphology. From the SEM of eroded surface the crater formation has been identified at different angle. The reason behind the crater formation is striking forces i.e. tangential force and perpendicular force. Low angle erosion confirms the ductility of the coating.

Acknowledgement

All the coating process have been done in Hindustan Aeronautics limited, Koraput division, India. All the experimental part has been done in NIT Rourkela.

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