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EFFECT OF COMPRESSIVE RESIDUAL STRESS ON TiAIN COATED HIGH SPEED STEEL VIA MICRO BLASTING

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ABSTRACT

The compressive residual stresses are particularly beneficial on the surface. It tends to increase fatigue strength and fatigue life, slow crack propagation, and increase resistance to environmentally assist cracking. Compressive residual stress can be achieved by coating process and surface treatment like blasting. Therefore, the research is concern on the behavior of compressive residual when applied coating followed by micro blasting on the surface. Titanium Aluminum Nitride (TiAlN) was deposited onto high speed steel substrate by reactive direct current (DC) magnetron sputtering with targets of titanium and aluminum. Thereafter the coated TiAlN was micro blasted with alumina (Al_2O_3) powder of the size of 48 μm applied to the coated surface to induce compressive residual stress. Taguchi method was utilized with four control factors of impact angle, time and distance between sample and blasting nozzle. Apart from that, the factors were also inclusive of four noise factors to get the most optimum condition. X-ray diffraction (XRD) analysis showed that TiAlN coating phase without blasting had lower compressive residual stress rather than the TiAlN coating phase combined with micro blasting. The results showed that micro blasting with alumina oxide powder increased 52.5% surface micro hardness and 57.6% adhesion strength of the TiAlN coated high speed steel.

Keywords: compressive residual stress, TiAlN coating, micro blasting, physical vapor deposition, Taguchi method.

INTRODUCTION

The introduction of PVD coatings for cutting tools in the metal cutting industry is one of the main success stories in the industrial application of modern coating technology over the last 30 years. The first PVD coating material to have a commercial application on cutting tools was TiN in the early 1980s and since the 1990s most cutting tools are PVD coated particularly in applications where sharp edges are required [1]. The TiAlN PVD coating is currently the most widely deposited PVD coating for cutting tools but other coatings such as TiCN and CrN offer better solutions in certain applications [2]. Many modern techniques have been developed to enhance the life of components in service, such as alloying additions, heat treatment, surface engineering, surface coating, implantation processes, laser treatment and surface shape design. Processes such as thin film technology, plasma spraying, vacuum techniques depositing a range of multi-layered coatings have greatly enhanced the life, use and applications of engineering components and machine tools [3,4]. The cleaning processes lead to changes in subsurface properties of the substrate. Requirements of coatings for wear protection in cutting are high hardness and sufficient toughness, as well as reduced tribological interaction with the workpiece material [3]. Mechanical pre-treatment processes, in addition to the chemical and sputter cleaning processes are often needed to enhance the coating adhesion.

To increase the cutting performance of tools, tool materials and their geometry have continually been improved. Requirements for coatings for wear protection in cutting are a high hardness and sufficient toughness as well as a reduced tribological interaction with the workpiece material [5, 6, 7]. The cutting tool performances have been improved by inducing compressive residual stress on the surface. The compressive residual stress on the surface will increase the wear resistance of cutting tools [8]. Thus, the combination of coating and micro blasting will be apply in this research as both technique will increase the compressive residual stress on cutting tool. In this research a relationship between compressive residual stress and mechanical properties of coated high speed steel will be establish and to prove that micro-blasting on coated high speed will enhancing the performance of cutting tool [3].

In the present paper, TiAlN PVD coating and blasted surface behavior have been evaluated separately due to the different method of preparation. The compressive residual stress behavior on the coated surface also has not been analyzed. Therefore, the aim of this research is to determine the compressive residual stress and identify the behaviors on HSS coated TiAlN embedded with sand blasting.

METHODOLOGY

Coating deposition

High speed steel (HSS M2) specimen of size 20 mm x 10 mm x 5 mm are used as the substrate material for the deposition of TiAlN coating. After that, surfaces of the HSS specimens are cleaned using ethanol via ultrasonic cleaning bath. Then, the surfaces are divided into 3 parts by using aluminium foil for characterization purposed. The layers of TiAlN were deposited on well-cleaned high speed steel substrates using a DC magnetron sputter deposition machine. In this research there are some changes from parameter in B.Subraniam *et al* [4] because some of the limitation of the magnetron sputtering PVD machine available. The setup for base vacuum was 1×10^{-6} Torr and operating vacuum is 1.5×10^{-2} Torr, whereby the sputtering gas is Ar and N_2, with the ration of 30 sccm: 10 sccm. The parameter are set as constant for all the samples. After the deposition, samples are still in the chamber to avoid any contaminant and oxide layer on the surface.

Micro blasting process

There are numbers of factors that can control micro blasting processes. However, the following parameter was selected to control micro blasting process: [A] Blasting pressure, [B] Distance between nozzle and sample, [C] Blasting time, [D] Impact Angle. The alumina powder size that has been used are 48 µm. From D.M Kennedy *et al* [5], the size of particles must be from 4 to 50 µm. The shape, density, durability and intensity also set as constant for all processes. The sample position was set as a noise factor in this research. The sample placed in horizontal condition or vertical condition.

The experiments are conducted using aluminium oxide (Al_2O_3) powder and are blasted by micro blasting machine. Desired pressures are set before run the experiment. A block are use to support the nozzle position to make it bombard the particles to the right place. The samples were hold by a clamper varied by its position horizontal or vertical. The clamper is also use to set the angle of impact by adjusting the position according to the level of experiment. After all the setup done, close the vacuum of blasting cabinet, then blast the sample based on the desired time blasting. The time is set by digital watch timer for 5, 10 and 15s. The sample was divided into 3 parts; uncoated, coated and coated-blasted for characterization purpose.

Surface characterization

Surface characterization is very important in order to identify it properties. A surface property is mainly measures due to its adhesion strength, cohesion strength, micro hardness and wear resistance. In this research, the surface characterization is focus on micro hardness and adhesion strength of micro blasted alumina on TiAlN coated HSS. Micro hardness Tester (Shimadzu Micro Harness Tester HMV-2Series) and Micro-Scratch Testing System (Wrexam, UK) were used to measure its hardness and adhesion strength. The data for each sample are compute to Taguchi design table to get the optimum condition of micro blasting that give the larger value. Characterization of surface is mainly focus on its compressive residual stress for uncoated, coated and coated-blasted surface. The compressive residual stress results are obtained from X-Ray Diffraction (XRD) analysis. The result is compared to determine the different between coated-blasted surface and coated surface due to their compressive residual stress. The main objective of this research is the study of compressive residual stress on coated high speed steel via micro blasting. The surface morphology study was obtained by scanning electron microscope (SEM).

RESULT AND DISCUSSIONS

Micro hardness

The level of each factor that is the most optimum factor are selected based on larger-the-better condition as shown in Figure-1(a). It shows the ranking of the most significant factor and the optimum condition for each factor. The level of each factor in mirco hardness test which is most optimum are A3 (4 bar), B1 (10 cm), C2 (10s) and D2 (90^o). While the most significant factor are factor A, followed by C, D and the most less significant are factor B. The Pareto chart are constructed to show clearly the ranking of NPM based on their contribution percentage of the process, which means the factor that get higher value will be rank as 1 and at last . The Pareto are shown in Figure-1(b).

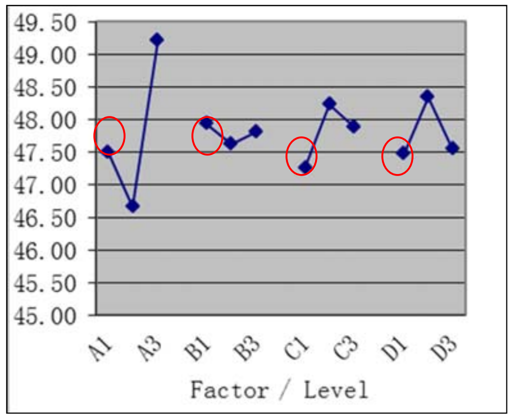

Figure-1(a). NPM response graph.

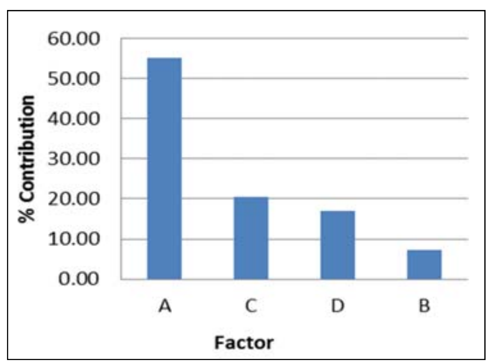

Figure-1(b). Pareto chart for micro hardness.

Adhesion strength

The level of each factor that is the most optimum factor are selected based on larger-the-better condition as shown in Figure 2(a) based on NPM analysis. It shows the ranking of the most significant factor and the optimum condition for each factor in Rank and Opt row. The level of each factor in adhesion strength test that is the most optimum are A2, B1, C2 and D3. While the most significant factor are factor C, followed by D, A and the most less significant are factor B. The Pareto chart are constructed to show clearly the ranking of NPM based on

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their contribution percentage of the process , which means the factor that get higher value will be rank as 1 and at last. The pareto are shown in Figure-2(b).

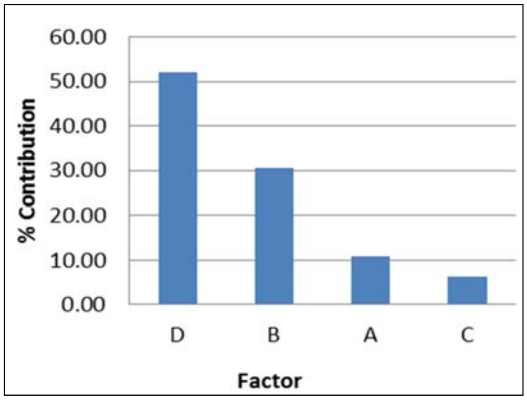

Figure-2. (a) NPM response graph.

In this research, the optimum condition and parameter of micro blasting process were obtained by Taguchi design method. There are two quality characteristic at the beginning or actual experiment which is micro hardness and adhesion strength. The main objective of this study is to investigate the behavior of compressive residual stress on coated-blasted surface.

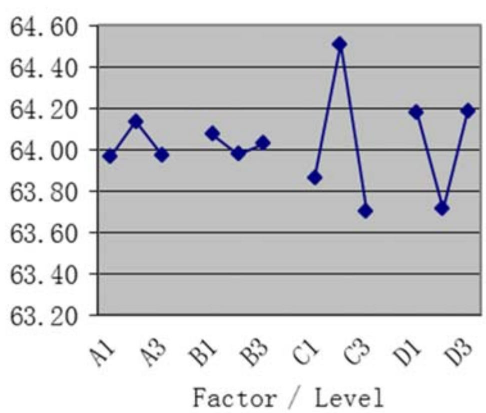

Figure-2(b). Pareto chart for adhesion strength.

However, there are some limitations to identify the compressive residual stress from the beginning of experiment. The relationship between hardness and adhesion strength with compressive residual stress which proportional to each other are used to define the optimum condition of micro blasting process. From the result of optimum hardness and adhesion strength, the best parameters are chosen and the compressive residual stress is defined for each set of parameter.

Taguchi design method results from hardness and adhesion strength give different set of parameter for the optimum condition. The optimum conditions in micro hardness test are the combination of 4 bar of blasting pressure, 10 cm of blasting distance, 10s of blasting time and 90° of impact angle. While in adhesion strength test, the optimum set of parameter are the combination of 3 bar of blasting pressure, 10 cm of blasting distance, 10s of blasting time and 45° of impact angle. The optimum conditions for each parameter in both characteristic are nearly the same due to the target of larger the better, because factor B and C give the same level of optimum condition. From this observations, a conclusion can be made which the characteristic of hardness and adhesion strength are proportional each other. Increasing in hardness will increase the adhesion strength of the material [9, 10].

Surface morphology

In surface morphology analysis, SEM was used to investigate the behavior of the surface in order to analyze the effect of micro-blasting of the coated surface. Micro blasting on the surface will create craters along the surface of high speed steel [11]. The crater profile on the surfaces increases the compressive residual stress because of the impact pressure from the shot material. The main stages involved in this dynamic process include elastic recovery of the substrate after impact, some plastic deformation of the substrate if the impact pressure exceeds the yield stress, increased plastic deformation due to an increase in impact pressure and finally some rebound of the shot due to a release of elastic energy [12, 13].

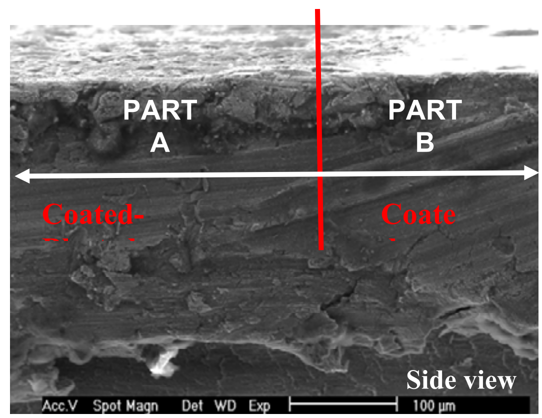

Figure-3(a). Part difference layer between coated-blasted and coated surface.

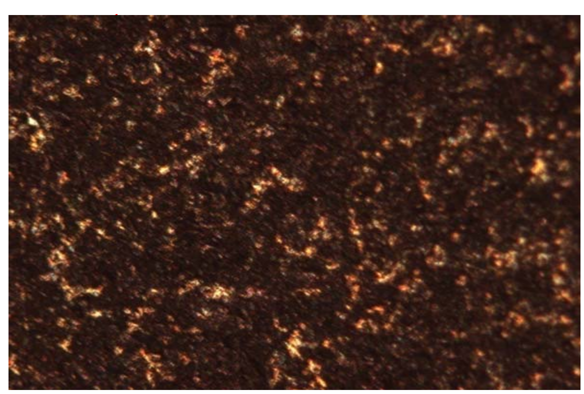

Figure-4 (a). Optical microscope image: Coated.

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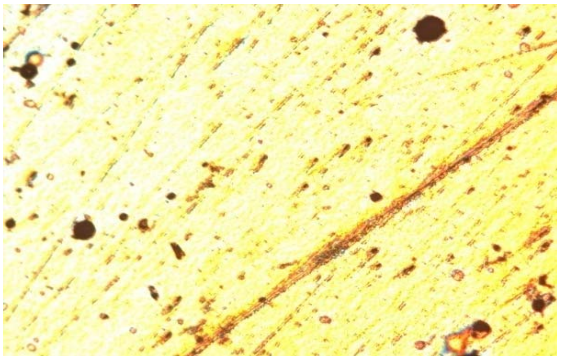

Figure-4 (b). Optical microscope image: coated - blasted.

From Figure-3(a), the images are taken at the intersection of coated and coated-blasted surface. This is to investigate the behavior and the difference between two surface characteristic. There are clearly different image of coated and coated-blasted surface. Part A are the coated blasted surface, while Part B is the coated surface. The direct image from the top of the surface also obtained using SEM. Figure-3(b) shows the coated surface image which the element of coating TiAlN occurred. The images of the surface are smooth. There are no craters on the surface. It shows the characteristic difference between the two surfaces. The brighter image on the coated-blasted surface as shown in Figure-4 are the TiAlN coating layer that have been coated before. It proved that there are no delaminations of coated surface after micro blasting process. The coated-blasted surface will increase the tool life of the surface as the wear resistance increase [14].

Compressive residual stress

The analysis of compressive residual stress are done on the coated surface and coated-blasted surface to evaluate the improvement of compressive residual stress. The microstrain broadening techniques ($b_{microstrain}$) was used to obtain the compressive residual stress.

$$b_{microstrain} = \frac{\text{Area under peak of highest peak}}{\text{Maximum peak value}}$$

When the area under peak are obtained, $b_{microstrain}$ are calculated by using above formula. The bmicrostrain are obtained for each sample. Then the strains (η) are defined by using $b_{microstrain}$ data because;

$$b_{microstrain} = - \eta \tan \theta$$

Where η is the surface strain and θ is the diffraction angle, get by dividing 2θ by 2. From the strain data, the stress can be obtained by using the following formula $\eta = 2\varepsilon$. ε is the micro strain. The stress is equal to young's modulus times micro strain as shown in following formula; $\sigma = E\varepsilon$. The stress of the surface (σ) is obtained this method. Estimation of the area under peak are using to defines the area by using basic mathematic technique. The four sample are blasted based on the optimum condition from micro hardness and adhesion strength testing. For sample 1 profile as shown in Figure 5 the area under curve are calculated;

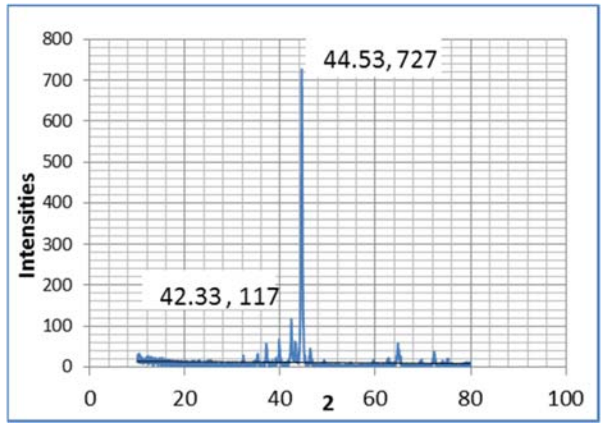

Figure-5. XRD pattern for sample 1.

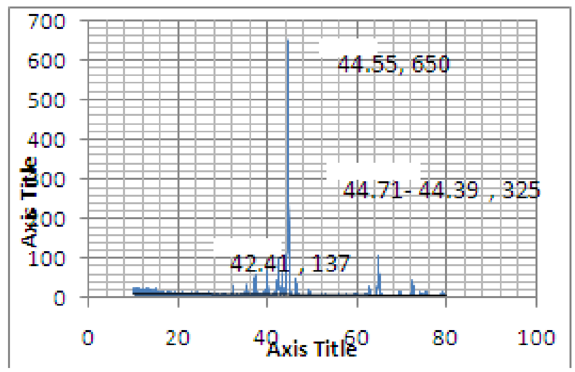

Figure-6. XRD pattern of sample 2.

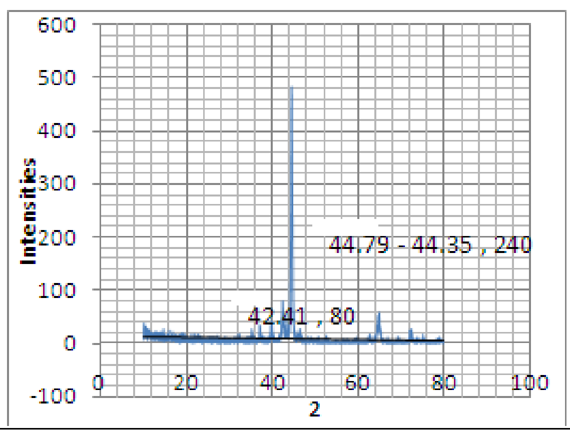

Figure-7. XRD pattern of sample 3.

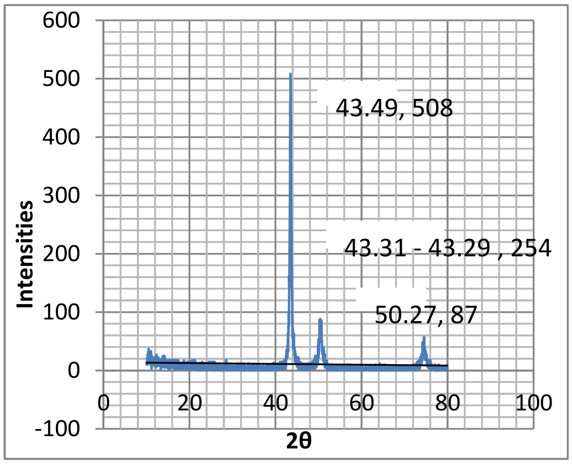

Figure-8. XRD pattern of sample 4.

For the coated surface as shown in Figure-9, same method and formula that are used in identification of compressive residual stress of coated-blasted surface are applied. The results are as follows;

From the calculation;
$b_{microstrain} = 0.69 \times 10^{-3}$ rad
$\eta = - 1.684 \times 10^{-3}$
$\varepsilon = - 8.42 \times 10^{-4}$
$\sigma = - 181.08$ MPa

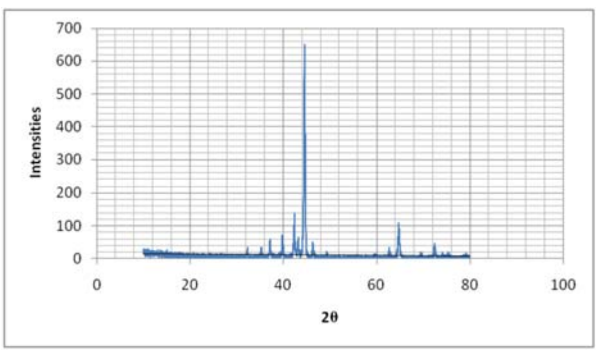

Figure-9. XRD pattern of coated sample.

The superficial mechanical properties of the applied coatings before and after micro-blasting, at various process parameters, were thoroughly investigated. K.D Bouzakis *et al* [2] stated that the coating possesses its pristine superficial nanohardness and mechanical strength, occurring after the physical vapour deposition. In micro blasting process with Al_2O_3, only a film material deformation, with negligible abrasion is expected to take place on its surfaces. From the experiments, shows that the coating layer is not delaminated when micro blasting process take places. The calculated compressive residual for each sample of coated-blasted and coated sample shows that the value of compressive residual stress for coated-blasted surface is higher than coated surface. From the previous research, the increasing in tool life of cutting tool are from coating process itself and the mechanical surface treatment like micro blasting, this have been stated by M.Klaus *et al* [6]. This is due to the generation of 'residual stress engineering' beneficial compressive stresses. In this research, the combination of these two processes absolutely will increase the cutting tool life and wear resistance [15]. In conclusion, micro-blasting improves the film strength properties, whereas coating surface integrity and adhesion remain practically invariant [16, 17].

CONCLUSIONS

Identification of compressive residual stress on coated and coated-blasted surface shows that the compressive residual stress of coated-blasted surface is higher than coated surface. It shows that the micro blasting process enhancing the compressive residual stress of coated surface. The combination of coating and micro blasting process lead to the increasing the tool life and increase the wear resistance of the surface. This research has shown that micro blasting of coated surface has a very positive effect on component surfaces by increasing toughness, operating life, improving hardness and surface finish. The results revealed a significant tool life increase through micro-blasting of coated surface. On the other hand, a comparable lower enhancement of the wear resistance can be attained through micro-blasting of coated surface.

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