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WEAR MECHANISM MAP OF MAGNESIUM ALLOY COATED WITH WC/CU ELECTRODE USING ELECTRO DISCHARGE ALLOYING

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ABSTRACT

The objective of this research is to study the wear mechanism of ZE41A magnesium alloy coated with WC/Cu material using EDC (Electro discharge coating). Dry sliding experiments were conducted with pin on disc method with different sliding condition such as normal load (1.5 kg - 3.5 kg), sliding speed (100rpm - 300 rpm) and sliding time (3min - 7min). Wear mechanism map was drawn against sliding condition of normal load and sliding speed which has been utilized to study the dominance of particular wear mechanism that dominates a particular wear regime. Different wear regime such as mild wear, severe wear ultra severe wear was developed by adjustment of contour line of the wear rate map. Various mechanisms such as abrasion, oxidation, delamination, plastic deformation and melting were observed in the worn surface.

Keywords: *Wear mechanism, Pin on disc, Wear regime, Mild wear and Abrasion.*

1. Introduction

Magnesium and its alloys are elegant for several engineering purpose due to good mechanical properties and low density. Though, the wear resistance of magnesium alloys is very poor in the critical environments [1, 2]. Furthermore, it is highly susceptible to wear when sliding contact with another metal. In practical applications, the poor corrosion and wear resistance of magnesium alloys often results in high maintenance costs or exclusion from other potential applications. A prospective way to improve the wear resistance of magnesium alloy, hard coating is possible. Combination of Tungsten carbide and copper is proposed as attractive materials for coating of magnesium due to superior wear resistance and electrical and thermal conductivity. Owing to dense protective carbide, magnesium alloy has good wear resistance in neutral environments. The following research articles have been focused on the wear behaviour of the different materials under different dry sliding condition.

Taltavull et al [3] studied the wear behaviour of AM50B magnesium alloy using pin on disc configuration on dry sliding condition with carbon steel as counterpart. From SEM microstructure studies, Abrasion and Oxidation mechanism were dominated at the lowest normal loads and sliding velocity.

Delamination and adhesion mechanism were dominated when increase the normal load and sliding velocities. The plastic deformation dominated at highest range of normal load and sliding speed. Similarly López et al [4] investigated the wear behaviour of ZE41A magnesium alloy using pin on disc technique with steel as counterpart. The sliding parameters such as sliding velocity and applied load on the wear rate and coefficient of friction has been studied. At lower sliding speed, oxidation mechanism and small participation of abrasion and delamination mechanisms were dominated regardless of the load. At higher speed, the main mechanism changed from abrasion at low loads and to delamination at intermediate loads and to plastic deformation at high loads. Rodrigo et al [5] improved the wear resistance of ZE41A magnesium alloy coated with Al–SiC composites using pin on disc apparatus. From the microstructure results, a thin mechanical mixed layer (MML) was appeared between the contact surface of the material and abrasion was the dominating the wear mechanism during this sliding condition.

In this paper, wear mechanism of ZE41A magnesium alloy coated with WC/Cu using electro discharge coating (EDC) under dry sliding conditions has been investigated. Wear mechanism map was drawn against sliding speeds and normal loads on the wear behaviour and performance were studied.

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2. Experimental details

2.1 WC/Cu coating on magnesium alloy

In this section, coating was produced on the surface of the magnesium alloy using electro discharge coating (EDC) with powder metallurgy (PM) electrode. Die sinking EDM (5530 EDM E-series) machine was used to coat the magnesium alloy in the present investigation. ZE41A magnesium alloy was utilized as workpiece and its chemical composition are Si-0.003, Cu-0.002, Zn-3.80, Zr-0.60, Fe-0.004, TRE-1.18, Ni-0.002, Mn-0.003, Al-0.006 and balance pure magnesium. Tungsten carbide and copper powder were selected as electrode material due to high strength and wear resistance and good thermal and electrical conductivity. The electrode with combination of WC70:Cu30 was prepared through powder metallurgy method for coating. During compaction of powder different loads were applied such as 150 MPa, 175MPa, 200MPa using punch and die with 10 mm diameter, further it was sintered about 600oC for 20 min using tubular furnace. The prepared WC/Cu cylindrical electrode was presented in fig.1. In the EDM process, two different parameters such as current (2A, 3A, 4A) and pulse on time (50µs, 70µs, 90µs) were selected to produce the coating on the surface using EDM oil as dielectric fluid. Finally the parameter was optimized using Minitab-16 software. These optimized parameters were found compaction load of 150MPa, current of 4A and pulse on time of 90µs.

Fig. 1 WC/Cu cylindrical electrode for EDC

2.2 Wear test

The wear tests were carried out on coated samples using pin on disc technique (TR-20-PHM-M1, Ducom, India). The samples were prepared with dimension of 10 mm diameter and 20mm length as presented in fig.2a for wear test. The counterpart disc was made by EN31 steel with hardness of 65HRC and it was polished with emery sheet grade of 1000 as given in fig.2b. Experiments were conducted as per Taguchi L9 orthogonal array with three factors three level and the pertinent dry sliding parameters was given in table 1.

Fig. 2 a) Wear test specimen b) Counterpart disc

Table 1: Experimental parameter and levels

Control factors	Unit	Level		
		I	II	III
Normal load	Kg	1.5	2.5	3.5
Sliding speed	RPM	100	200	300
Sliding time	min	3	5	7

3. Result and Discussion

3.1 Wear mechanism map

Wear map can be constructed systematically by using consistent database, once constructed will provide a material selection guide as well as a design guide for an engineering application. One can also classify the wear processes by using the wear map approach which allows one to conduct critical experiments in the right combination of material, operating condition, and environment to investigate the different wear mechanisms. The present study focuses to develop wear mechanism map for the surface of magnesium alloy coated with WC-Cu composite material produced through powder metallurgy route using EDC. In conventional empirical wear mechanism maps, it is difficult to establish the boundaries of different mechanisms. Hence it is decided to use MINITAB programs by plotting the normal load on the Y-axis, the sliding speed on the X-axis, and the values of wear rate on the Z-axis. The different field boundaries on the map suggest where transitions of one dominant wear mechanism to another may take place. The physical wear mechanism maps need extensive physical modeling for determination of boundaries for different mechanisms. In empirical maps, the boundaries are constructed roughly based on the observations of the worm out surface. Because of the wide range of sliding velocity and contact pressure covered by the map, it should enable the designer to decide intelligently whether the material under study will be able to meet the set of requirements for a particular tribological application. In view of engineering side, mild wear regime has been consider good enough or satisfactory but the severe wear and ultra-severe wear regimes are considered unacceptable. Wear mechanisms such as abrasion, oxidation, and delamination, plastic deformation and melting were observed test conducted in different parameter conditions as shown in fig.3. The mild wear is observed in the sliding speed range of 100 to 250 RPM and normal load of 1.5 to 3kg. This wear takes place by mechanically forming fine wear debris. This is detached from the surface as thin flakes. It usually occurs in systems involving hard particles in motion relative to a surface. The worn out surface taken from the mild wear shows mostly grooves, indicative of micro abrasion being the dominant wear mechanism. Abrasion of the hard metals with the abrasives results in wear of the binder phase is more rapid than that of the carbide phase and that carbide pullout is a significant mechanism of wear with these abrasives. This wear mechanism predominates in the low normal load and sliding speed [7].

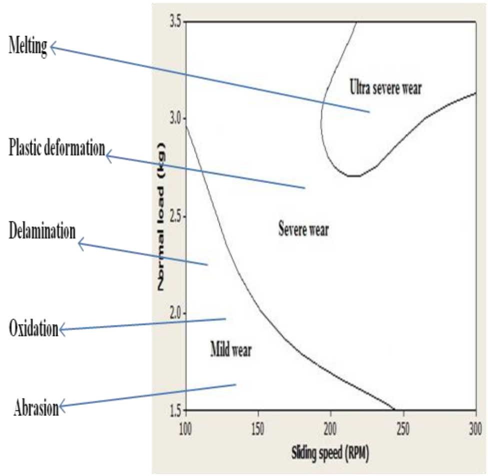

Fig. 3 Wear mechanism map of coated magnesium alloy

The formation of oxidation was occurred in the mild wear regime when test conducted in the sliding conditions of low load (1.5 kg) and sliding speed (200RPM). The origin of oxidative wear lies in the own oxidation sensitivity of Mg alloys that is enhanced by means of frictional heating caused by sliding. Coated Magnesium alloys strongly tend to oxidation even in the absence of aggressive conditions. Hence, it is possible that the oxidation wear may play an important role in this behaviour of material [8].

The occurrence of this oxidation layer prevented from metallic contact and resulted in small wear rates. At low load and intermediate sliding speed, delamination mechanism was formed which occurred in mild wear regime. This owing to during the wear process subsurface cracks grow and combination with cracks perpendicular to the sliding direction cause the detachment of sheet-like fragments of the worn material. These volumes are equivalent to voids observed in the pin surface, confirming that delamination was the predominant wear mechanism [9].Severe wear was noticed in the normalized sliding speed range of 250 to 300 RPM and normal load of 3 to 3.5 kg. Micro fracture and brittle fracture have become the dominant wear mechanism in these conditions. This due to initial wear rate and friction coefficient are high as the pin penetrates the counter surface, then they decrease till a nearly constant value is reached, corresponding to a regime condition with wear increasing almost linearly with sliding distance. The surface micro cracks and integrity of the machined surfaces are directly related to material removal mechanisms. The formation of the craters in EDCed surfaces is due to sparks that form at conductive phase generating melting or possible evaporate and remove the copper material. The released grains are deposited in the machined surface which leads micro cracks, craters are formed and it will be removed by micro fracture and brittle fracture. At high normal load and sliding speed, grooves caused by abrasion cannot be observed and that the surface of the samples was clearly deformed [10]. When the loading was increased beyond 3kg and sliding speed beyond 250RPM, a transition of the wear regime from severe wear to ultra-severe wear took place. The thermal shock induced wear is observed in this condition. During sliding high temperature produces which resulted the formation of melting material. When continuous sliding on melted material which spread out in the contact surface in the sliding direction. Further increase in normal load and sliding speed causes high contact temperatures between pin and disc and also increase in frictional heat which results the surface melting [11]. The transition from severe wear to ultra severe wear is also controlled by normal load and sliding speed.

4. Conclusions

Pin-on-disc wear tests of WC/Cu coated magnesium alloy were investigated against EN31 steel counterface with different sliding condition. The wear rate increases with increase in normal load and sliding speed. From the wear map it was revealed that the sliding wear behaviour of WC/Cu coated ZE41A magnesium alloy can be classified in to three wear regimes, namely mild wear, severe wear and ultra severe wear. The dominant wear mechanisms in each regime were identified and summarized in the wear mechanism map namely abrasion, oxidation, delamination, plastic deformation, and melting. From the study, abrasion occurs at 1.5 kg and 100RPM, oxidation occurs at 1.5 kg and 200RPM, delamination occurs at 1.5kg and 300 RPM, plastic deformation at occurs 2.5kg and 200RPM and melting mechanism occurs at 3.5kg and 300RPM.

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