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Influence of Trace Addition of Cd on the Tribological Characteristics of 2219 Al Alloy at Different Working Conditions

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Abstract—*2219 Al alloys are potential structural materials for aircraft and space applications, due to high strength to weight ratio. Microalloying (< 0.1 wt.%) with trace elements such as Sn, In, Cd, Ag, Si, etc. results still better mechanical properties avoiding considerable increase in weight. Due to lesser surface hardness of Al, tribological study of such alloys is important. The effect of microalloying with 0.06 wt.% Cd on the tribological behaviour of cast 2219 Al alloy is investigated. Dry sliding wear tests were conducted with different loads and sliding speeds. Volumetric wear rate increased, but the friction coefficient decreased with increasing load and sliding speed. The volumetric wear rate and friction coefficient of the alloy decreased by 78.6 % and 26.4 % respectively due to addition of Cd, imparting a superior wear resistance, correlated with the strength and hardness.*

1. INTRODUCTION

The need for advanced materials with superior properties has led to the development of many new alloys. The search for new materials with enhanced properties for industrial and structural applications has led to the development of many metallic alloys. A metallic alloy is a solid solution made of two or more metal elements or metal and non-metal elements in a metallic matrix. Alloys can be a homogeneous solid solution, a heterogeneous mixture of tiny crystals, a true chemical compound, or a mixture of these [1]. Alloys tend to have properties which often happen to be superior to that of their constituent elements. Ferrous alloys are the most widely used materials for engineering applications due to their favourable mechanical properties that can be tailored by heat treatments and/or mechanical working [2]. However, in light weight applications, especially in aircraft and space related areas, the high density of the ferrous alloys compared to non-ferrous alloys such as titanium, aluminium, and magnesium restrict their use. The high demand in aircraft and space industry for lighter structural materials has resulted in a thrust in development of light weight alloys exhibiting better mechanical properties over the decades. Out of these light weight alloy systems, the wrought and precipitation strengthened aluminium alloys such as Al-Cu, Al-Mg-Si, and Al-Cu-Zn-Mg alloys have been the most promising alloys. The strengthening of these alloys after deformation is achieved by age hardening (or precipitation hardening). It is now well established that precipitation of extremely small and uniformly dispersed hard second phase particle in the alloy matrix enhances the strength and hardness of these alloys [2].The present research trend to develop increased strength of these materials along with reasonable toughness and low density is by the addition of trace elements (microalloying, i.e. < 0.1 wt.%) likeSn, In, Cd, Ag, *etc.*[4,5,6,7] in to the alloy matrix. Literature is available regarding the influence of several alloying elements on the structure and properties of some commercial aluminium alloys. However, investigations on the effect of microalloying on the heat treatable 2xxx series of aluminium alloys are still limited in number. Wear is a process where interaction between two solid surfaces within the working environment results in the removal and deformation of material on a surface as a result of mechanical action of the opposite surface. Several aspects of the working environment which affect wear include loads and features such as unidirectional sliding, reciprocating, rolling, and impact loads, speed, temperature, but also different types of counter-bodies such as solid, liquid or gas and type of contact ranging between single phase or multiphase, in which the last multiphase may combine liquid with solid particles and gas. Material scientists have been in constant search for materials with good wear behaviour. The primary problem of aluminium alloys is their poor wear characteristics.Researchers have focused their attention in developing new advanced materials like metal matrix composites for overcoming the poor wear properties of aluminium alloys. Aluminium metal matrix composites have proved useful for a variety of engineering applications because they exhibit superior stiffness, wear and high temperature performance compared to its matrix alloy. Though microalloying also exhibit similar properties, exhaustive research regarding their wear performance is not done yet. This research piece deals with the investigation of the wear behaviour of 2219 Al alloys microalloyed with Cd with the help of dry sliding tests. Therefore the investigation gives valuable insight into the effect of trace addition of Cd on the tribological behaviour of 2xxx series of aluminium alloys.

2. EXPERIMENTAL DETAILS

Rectangular plates of 2219 Al-Cu-Mg alloys (Al-6.2%Cu0.02%Mg) and the same alloy with trace additions of Cd (0.06 wt.%) were prepared by casting route in a resistance heated melting furnace using rectangular mild steel moulds. The details of the casting procedure have been discussed in a previous research work on microalloyed Al-Cu-Mg alloys [9].The alloys are designated as Alloy-A and Alloy-B respectively for 0 and 0.06 wt.% of Cd additions. The plates were machined to remove the thin cast surface features which may result in surface defects. They were machined to obtain cubical samples of $10 \times 10 \times 10\ mm^3$ and were ground on 800 grid emery paper to have uniform standard surface since surface finish of the specimens would influence friction and wear characteristics. The prepared samples were then subjected to homogenizing heat treatment in a muffle furnace at 510°C for 10 hours to reduce chemical segregation of cast structures and to improve their workability. Finally, the prepared samples were cleaned using cotton and acetone to remove dirt particles. Dry sliding wear tests of the prepared samples were conducted on a Pin-on-Disc Tribotester (Model: DUCOM TR-20LE). The prepared cubical samples of $10 \times 10 \times 10\ mm^3$ were used as pins and tested against a 8mm thick disc of diameter 165mm made of hardened ground steel (En31 hardened to 62HRc) under ambient conditions. The specimen was held stationary in the sample holder and the disc was rotated against it. As the disc rotated loads were applied through a lever mechanism. The tests were conducted with four normal loads viz. 1kg, 2kg, 3kg and 4kg and four sliding speeds viz. 0.5m/s, 1.25m/s, 2m/s and 2.5m/s. Abrading time for all the tests were kept constant at 150 sec. Before and after the wear test, weights of the test specimens were measured using an electronic balance (Make- Mettler Toledo, Model – AB265-S/FACT) having least count of 0.03 mg. Cares have been taken after each test to avoid entrapment of wear debris. The volumetric wear rate was estimated by measuring the mass loss (ΔW) after each test. The theoretical density of the 2219 Al alloy has been taken as 2.84 gm/cc.

Table 1: Different loads and sliding speeds selected for conduction of wear tests.

Sl. No.	Loads (kg)	SlidingSpeeds (m/s)
1	1	0.5
2	2	1.25
3	3	2
4	4	2.5

The volumetric wear rate (W_v) of the sample is related to density (ρ) and the abrading time (t), by the equation,

$$W_v = \Delta W / \rho\ t \quad (1)$$

The frictional force was measured for each pass and then averaged over the total number of passes for each wear test. The average value of friction coefficient (μ) of the specimen was calculated from the equation,

$$\mu = F_f / F_n \quad (2)$$

where, F_f is the average frictional force (in N) and F_n is the applied load (in N).

3. RESULTS AND DISCUSSION

3.1. Variation of Volumetric Wear Rate with Sliding Speed and Applied Load

Fig. 1 (a) and (b) show the variation of volumetric wear rate with the variation of experimentalsliding speeds (viz. 0.5m/s, 1.25m/s, 2m/s and 2.5m/s), at different load values, for Alloy-A and Alloy-B respectively. The volumetric wear rate increased with increase in sliding speed for any given load.For both the investigated alloys, the volumetric wear rate was observed to be somewhat saturated at lower sliding speeds up to 1.25m/s, but increased more rapidly with a higher gradient with further increase in sliding speed. However the wear rate again becomes saturated to some extent for the Alloy-B, at higher values of sliding speeds above 2 m/s.

Fig. 2 (a) and (b) reveal the variation in volumetric wear rate with the variation of applied load (viz. 1kg, 2kg, 3kg and 4kg), at different sliding speeds, for Alloy-A and Alloy-B respectively. The volumetric wear rate increased with increase in applied load, for a given sliding speed.

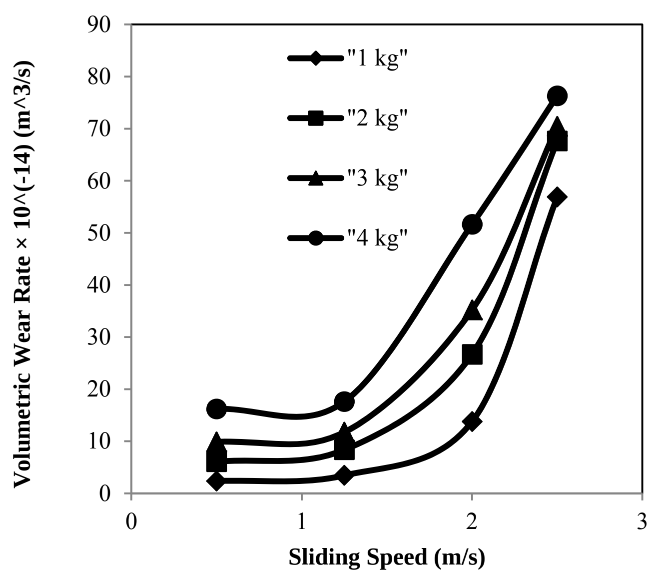

Fig. 1(a) Variation of volumetric wear rate vs. Sliding speed for Alloy-A

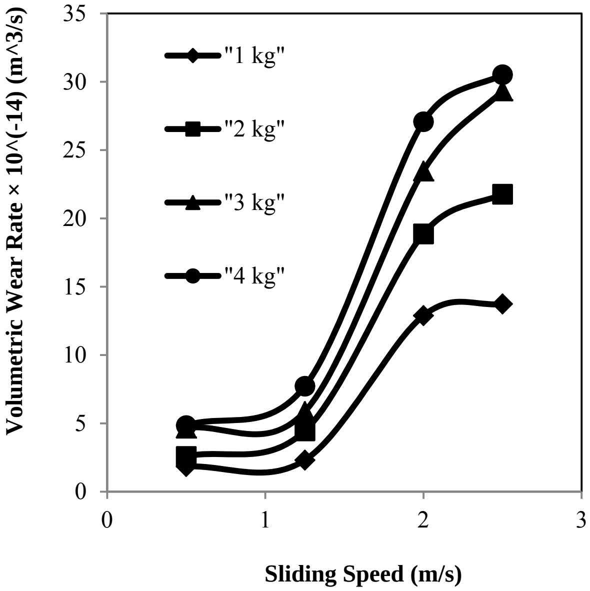

Fig. 1(b) Variation of volumetric wear rate vs. sliding speed for Alloy-B

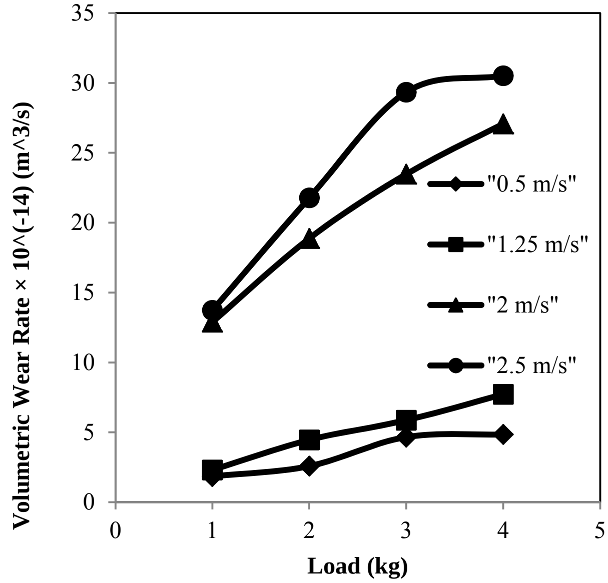

Fig. 2(b) Variation of volumetric wear rate vs. load for Alloy-B

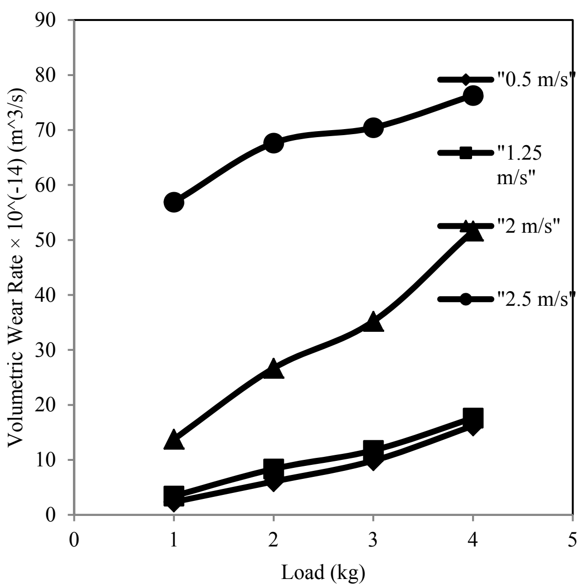

Fig. 2(a) Variation of volumetric wear rate vs. load for Alloy-A

3.2.Variation of Friction Coefficient with Sliding Speed and Applied Load

Fig. 3 (a) and (b) show the variation in friction coefficient with the variation of sliding speed and load respectively, for Alloy-A. However for both the investigated alloys, the friction coefficient decreased uniformly with increase in both sliding speed and load.

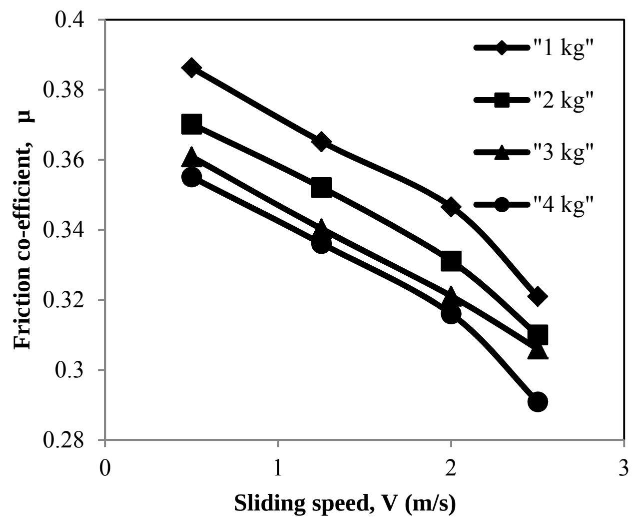

Fig. 3(a) Variation of friction coefficient vs. sliding speed for Alloy-A

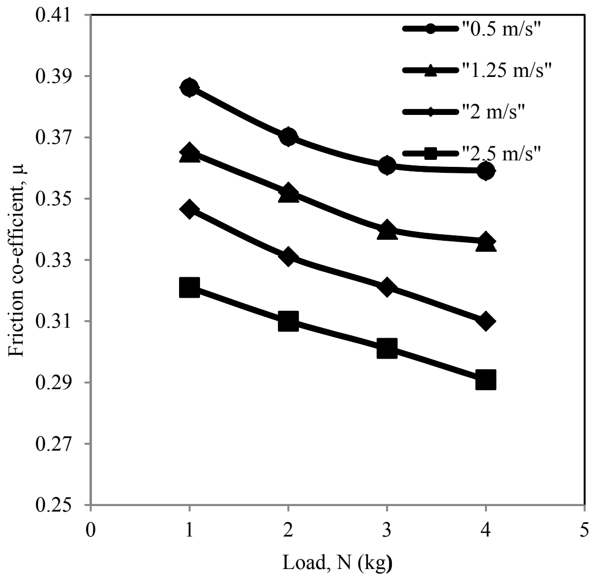

Fig. 3(b) Variation of friction coefficient vs. load for Alloy-A

3.3. Influence of Trace Addition of Cd on the Volumetric Wear Rate and Friction Coefficient

The volumetric wear rate and friction coefficient values have been compared for both the alloys at given test conditions of sliding speeds and loads. It has been observed that there is an average decrease in volumetric wear rate by 78.6 %, due to trace addition of 0.06 wt.% of Cd, considering different conditions of loads and sliding speeds. Similarly the friction coefficient was observed to have decreased by an average of 26.4 %, due to microalloying with Cd. Moreover as already discussed, the wear rate increased with a slower rate due to addition of Cd, for higher sliding speeds.

The decrease in both of volumetric wear rate and friction coefficient ensures improvement in surface wear resistance, after microalloying with 0.06 wt.% of Cd. In another research work conducted parallelly, it has been observed that there is a considerable increase in strength and hardness of the 2219 Al alloy, due to addition of 0.06 wt.% of Cd. Hence the increase in wear resistance may be attributed to the increase in surface hardness of the base alloy due to microalloying with Cd. The similar increase in wear resistance of this alloy was also observed after adding trace contents of Sn [10]. Thus it is evident that for all test conditions, the tribological behaviour of 2219 Al alloy gets improved due to trace addition of Cd.

4. CONCLUSION

The wear rate considerably increased while the friction coefficient uniformly decreased with increase in sliding speed, as well as operating load. However, both the values of volumetric wear rate and friction coefficient decreased by 78.6 % and 26.4 % respectively, due to trace content of 0.06 wt.% of Cd. Decrease in the above values ensures that microalloying with Cd imparts superior tribological characteristics to 2219Al alloy, by improving the surface wear resistance of the alloy.

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