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The friction coefficient evolution of a MoS₂/WC multi-layer coating system during sliding wear

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Abstract. This paper discusses the evolution of friction coefficient for the multi-layered Molybdenum Disulphide (MoS₂) and WC coated substrate during sliding against Aluminium AA 6082 material. A soft MoS₂ coating was prepared over a hard WC coated G3500 cast iron tool substrate and underwent friction test using a pin-on-disc tribometer. The lifetime of the coating was reduced with increasing load while the Aluminium debris accumulated on the WC hard coating surfaces, accelerated the breakdown of the coatings. The lifetime of the coating was represented by the friction coefficient and the sliding distance before MoS₂ coating breakdown and was found to be affected by the load applied and the wear mechanism.

1. Introduction

Aluminium sheet metal forming attracts great interest from manufacturing industries in providing light weight components with high strength. However, studies suggest that the interaction between tools and Aluminium workpiece surfaces where adhesion and transferring of Aluminium on tools takes place decreases the surface quality of the finished product and damages the tool [1]. As a result, lubricant and coating are required for sheet metal forming processes especially in operations such as ironing and stamping [2].

The aim of this paper is to explore the friction and wear of an advanced coating system, where Molybdenum Disulphide (MoS₂) and WC were combined as a multilayer coating to reduce the adhesive wear in Aluminium forming process. The tribological properties of Molybdenum Disulphide are maintained at high temperatures up to 400°C, thus making it one of the most desirable lubricants to be used in warm forming. The WC, as the hard layer coating, has high resistance to thermal shock, which gives itself the ability to withstand rapid temperature fluctuations when sheet metal is in contact with the tools. The material also has the ability to withstand high compressive stresses, providing additional support to the soft MoS₂ coating.

2. Material and Experimental Method

2.1. Multilayer coating strategy

WC was applied through ultrasonic flame spray, a method where ultrasonic waves propagated and ensured precise application of coating without the need of direct contact to the material [3]. MoS₂ was



applied at a later stage through film spray, which created the multilayer coatings on the G3500 cast iron substrate shown in Figure 1.

The specimen was examined through friction tests against an aluminium AA 6082 pin of radius 2.5 mm. The pin was in direct contact with the thin soft film of Molybdenum Disulphide and WC hard coating when the film broke down. The thickness of the MoS₂ film was approximately 25-30 µm and classified as a thick coating. The WC film on the other hand was 60-70 µm thick and the spraying method used allowed a more even coating distribution comparing to the MoS₂ film.

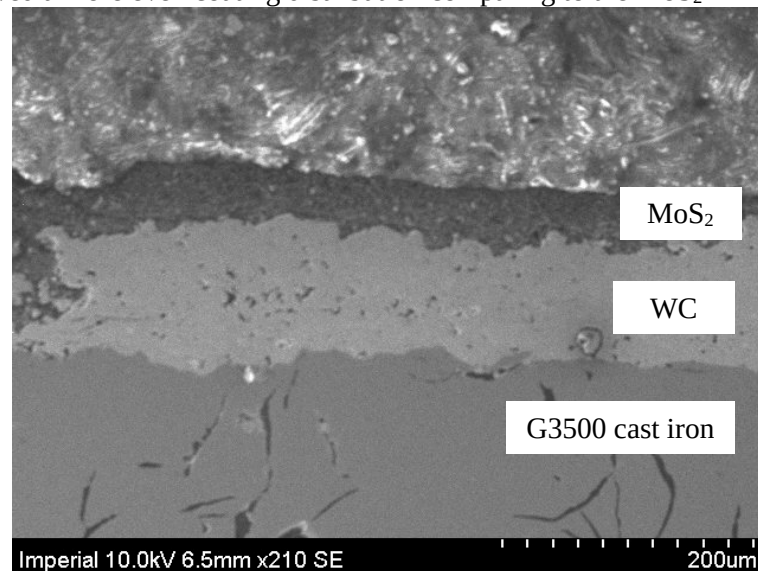


Figure 1. SEM image of Specimen Cross Section.

2.2. Friction Coefficient Test (Pin-on-disc set up) & Surface Analysis

A THT tribometer [4,5] was used to for the friction tests to assess the time, distance the pin travelled with respect to the plate and the coefficient of friction. These parameters were used to compare the evolution of friction under various circumstances.

Different loads were applied to investigate the effect on the lifetime of the coating, which was determined by the sliding distance before the occurrence of break-down. The loads applied were 1N, 3N, 7N and 9N at a sliding speed of 10 mm/s.

The optical microscope was used to analyse the topography of the specimen. It was particularly useful in observing the type of debris and wear left behind on the wear track and hence suggesting the friction mechanism taken place during the process. Moreover, Scanning Electron Microscope (SEM) was used to extract the thickness of the specimen's coating.

3. Results and Discussion

The tribological relationship was largely affected by the mechanical property of the coating and substrate as well as the size and hardness of debris in contact. Figure 2 shows the evolution of the average coefficient of friction under different loads on the MoS₂ soft coating lifetime before its breakdown.

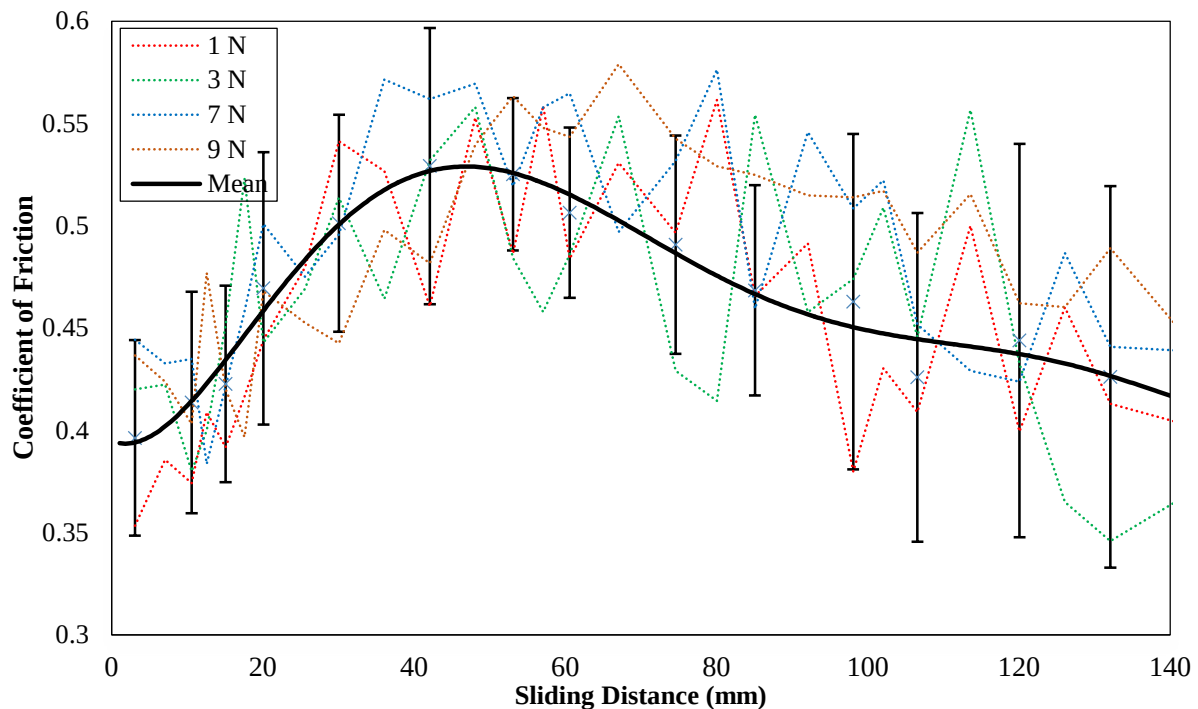


Figure 2. Mean Friction coefficient with error bars against sliding distances under 1N, 3N, 7N and 9N load.

The mean friction coefficient showed a rapid increase from 0.4 to 0.5 within a sliding distance less than 40mm. However, the effect of load on the friction coefficient evolution was not clear as the thick MoS₂ layer was penetrated very soon after the experiment started and gave a gradually increasing value of the friction coefficients. Low friction coefficient could be obtained through the introduction of multilayer coating at the initial stage. In comparison to aluminium and cast iron direct contact, the shear strength was reduced significantly through the usage of MoS₂. The low hardness of MoS₂ (400 HV) would imply a larger contact area between the aluminium slider and its surface and hence the reduction in friction through lower friction force was compromised by the increase in normal force due to the increased contact area. However, the combination of MoS₂ and thick metal layer would increase the hardness of the soft coating hardness to 1000 – 2000 HV [6]. This would result in a lower overall friction coefficient as lower shear strength was achievable without increasing the contact area.

The soft MoS₂ coating underwent rapid adhesive wear off, leading to an increase in friction coefficient within a short sliding distance. The lower platform at the beginning of figure 2 suggested the effect of MoS₂ in friction coefficient reduction. The soft coating soon experienced elastic and plastic deformation during the sliding and faced an increase in friction due to ploughing by the wore-off particles.

After reaching its peak at 40mm for 0.55, the friction coefficient experienced a gentle reduction while remaining higher (0.45) than the lower platform (0.4) experienced at the beginning. This phenomenon was observed as MoS₂ particles acted as a solid lubricant, when the soft particles were entrapped between surfaces while the ploughing forces from the MoS₂ were no longer present when particles were entrapped between the contact of the slider and hard coating. The differences in load are suggested to have little impact on the breakdown time of the MoS₂ soft coating due to the relatively little variation in the coefficient of friction. However, the increased fluctuation shown as the error bar at higher sliding distance suggested the difference in friction experienced by the WC coating. This predicted that the WC hard coating would experience breakdown while the lifetime of the WC hard coating will vary due to the difference in loads [7].

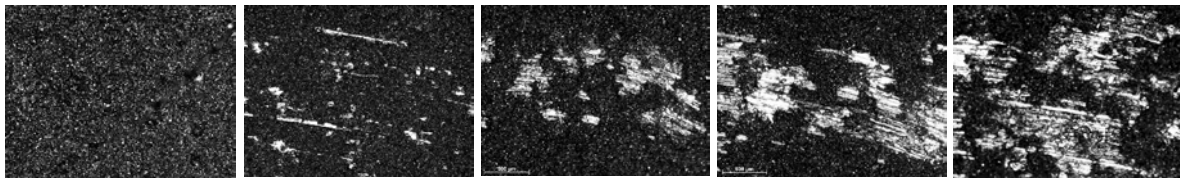


Figure 3. Specimen surfaces under various load: before the test, 1N, 3N, 7N, 9N (Left to right).

The wear track from Figure 3 suggested higher wear rate with increased loads. The surfaces were shown to have larger area of WC exposed as well as aluminium debris accumulation. This could be well-explained by the penetration of the soft coating due to the roughness of aluminium. Higher load increased the penetration area and resulted in higher wear rate during the friction test under the same distance travelled.

Aluminium debris was only observed along the wear track where WC coating was exposed. This proposed the benefit of MoS₂ soft coating on the reduction of material transfer, as almost no aluminium debris could be found over the presence of this soft coating. On the other hand, aluminium debris accumulated on the WC hard coating surfaces would lead to a rise in friction coefficient through a type of anchoring mechanism resisting motion. Due to the increased exposure of WC area with the increased load, an increase in aluminium debris was also shown at higher load.

The rapid wear off of the MoS₂ coating shows the ineffectiveness of the soft coating itself. To obtain more effective Aluminium sheet metal forming, application of MoS₂ spray is required for every stamping operation. This would require a lower punch force due to the lower friction achieved and would prevent the wear off of aluminium and accumulation of debris.

4. Conclusion

The MoS₂ coating on WC hard coating allows lower punch forces to be required in aluminium sheet metal forming while providing a better surface finishing. The coating prevents the accumulation of aluminium debris on the tool surfaces. However, due to the short lifetime of the soft MoS₂ coating, this requires the MoS₂ to be applied by a spraying method after each forming process, despite the fact that the MoS₂ debris would still be able to partially protect the tool surface.

5. References

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