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Study of Fretting Fatigue Behavior of Cylinder head Aluminum Alloy, with and without nano-Clay-Particles

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ABSTRACT: Fretting fatigue occurs when contact stresses cause cracks to form and continue to grow between two objects or surfaces in contact. By considering frictional fretting and cyclic mechanical loads, the phenomenon of fretting fatigue can occur in vehicle engine parts. The presence of cyclic loads and the presence of fretting in the engine cylinder head increase the probability of the fretting fatigue phenomenon. In this study, the effect of lubrication and the fretting force value on the fretting fatigue behavior of the aluminum alloy used in the cylinder head has been investigated. The results were also obtained to compare samples with and without nano-particles. In addition, microstructure and fracture surface were examined by optical microscopy and field emission scanning electron microscopy. The results showed that lubrication could reduce the fretting damage. Moreover, increasing the fretting force decreased the fatigue lifetime of the sample with nano-particles. According to the results obtained from the tests, the effect of nano-particle amplification on the aluminum alloy with and without lubrication and at the fretting force equal to 15 N, increased the fatigue lifetime by about 50 times.

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1- Introduction

Fretting is a relative tangential motion often referred to as small-scale movement that occurs between two objects or surfaces in contact when subjected to vibrational loads or variable forces. Fretting Fatigue (FF) occurs when contact stresses cause cracks to form and continue to grow between two objects or surfaces in contact. In previous studies, nano-particles have been used as a material to enhance mechanical properties [1-7], which can be considered as one of the methods to strengthen aluminum by adding nanoparticles, but the effect of nano-particles on FF has not been sufficiently investigated. In this article, the effect of adding nano-particles to the cylinder head aluminum alloys in the FF tests was demonstrated. The research on FF has shown that rotary-bending fatigue test machines could use to perform the FF tests [5]. Furthermore, the effect of fretting force and lubricant on the FF lifetime is rarely investigated. Moreover, the effect of fretting force and lubricant on the samples with and without nano-clay-particles had been compared.

2- Materials and Experiments

The base material used in this research is aluminum-silicon-copper alloy, which according to previous research [1] is widely used in the manufacturing of automobile cylinder heads. Moreover, the nano-clay-particles have been used to reinforce the as-cast material [1]. The FF test was also performed by applying lubricant on each material at a stress level of 100 MPa to indicate the lubrication influence on the FF lifetime. Furthermore, the fretting pads used in this research have been extracted from the real piston rings. The amount of contact force between the fretting pads and the test specimen selected is equal to 10 and 15 N.

3- Results and Discussion

Regarding the microstructure discussion, Fig. 1 shows the microstructures of cylinder head aluminum alloys, with and without nano-particles used in this research. Due to the microstructures of the samples, various phases such as the silicon phase and the α-Al phase are observed in Fig. 1. To investigate additional details, samples of aluminum alloys in completely random areas with 200X magnification have been studied using the ImageJ software. The results showed that in all heat treatments, the eutectic phase of silicon was reduced compared to the original alloy. However, in the case of the aluminum-copper phase, no specific conclusion could be made with high certainty. This phase made the alloy highly sensitive to any temperature changes. Increasing the surface area of the aluminum-copper phase was one of the most important reasons for reducing the hardness.

The results of the FF test are illustrated in Fig. 2. This figure compares the FF lifetime of as-cast aluminum alloy and nano-composites with lubrication and non-lubricated

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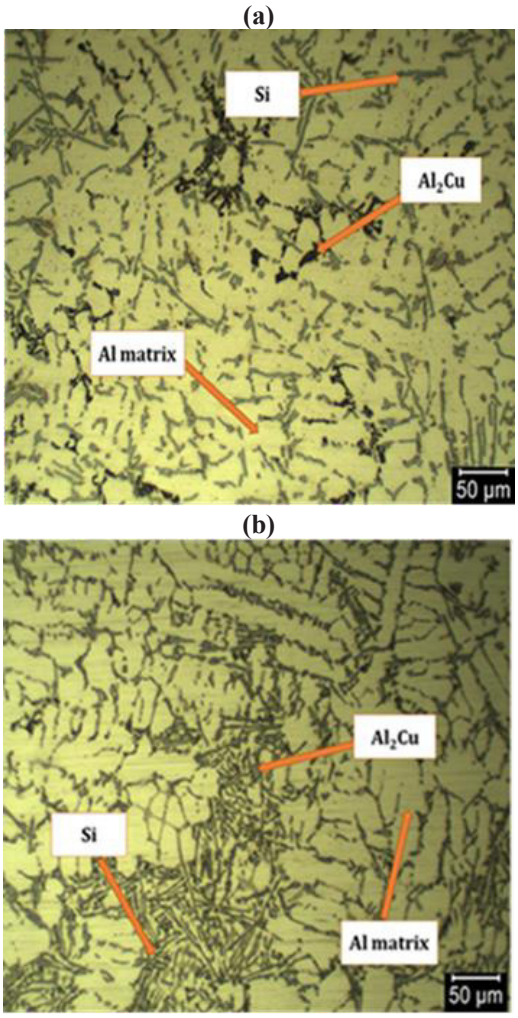

Fig. 1. Aluminum alloy microstructures: (a) without nano-particles and (b) with nano-particles

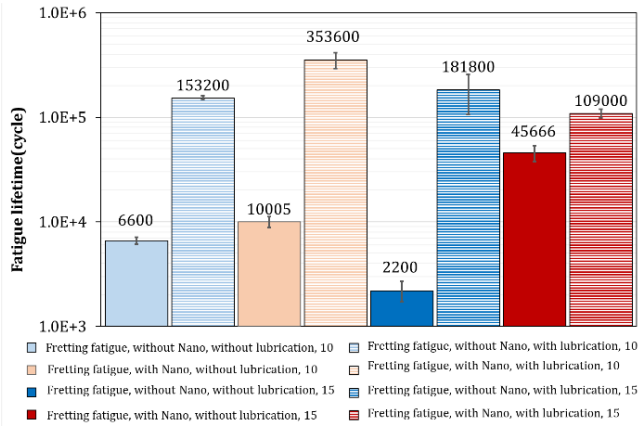

Fig. 2. The effect of the lubricant addition on the FF lifetime of the aluminum alloy

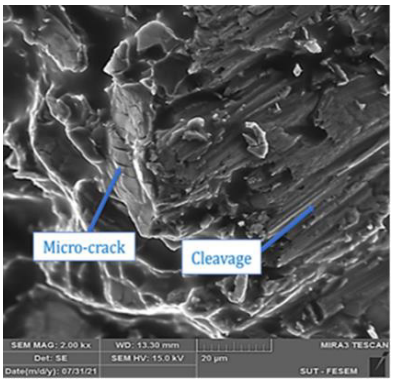

Fig. 3. FESEM images from the fracture surface of the sample with nano-particles and the lubrication at 15 N

condition. The results illustrated that the FF lifetime of the nano-composites increased 2.3 times, compared to the samples without nano-particles in lubrication conditions with a 10 N fretting force.

Furthermore, in the non-lubricated test samples with 10 N of the fretting force, the FF lifetime of the specimens with nano-particles was obtained to 1.5 times increasing, compared to samples without nano-particles. The FF lifetime of the specimens with nano-particles was reduced 1.6 times, compared to the sample without nano-particles in lubricated conditions and at the fretting force of 15 N, while in the conditions without lubrication and at the previous force, the FF lifetime of the samples with nano-particles decreased, which increased 50 times, compared to the sample without nano-particles.

In addition, the fracture surfaces were also investigated by Field-Emission Scanning Electron Microscopy (FESEM). According to Fig. 3, the results demonstrated that for the as-cast material and the nano-composite, after the addition of lubricant and increasing the FF lifetime, the size of the cleavage plates has significantly increased. Moreover, the number of quasi-cleavage marks has decreased. The maximum thickness of the damaged area due to wearing and the total area of this region have been measured and the results showed that the reduction of the fretting force and the addition of lubricant during FF testing, increased the maximum thickness of the damaged area by about 0.026 mm for the sample without nano-particles. The mentioned term was about 0.018 mm for the sample with nano-particles.

As mentioned, FESEM images were used to investigate the effect of different elements and phases on the failure of the material. Moreover, the Energy Dispersive X-Ray (EDX) map analysis was performed on the failure levels of the material. The examination of these images depicted that the silicon phase and intermetallic phases were present at the fracture level of all samples.

4- Conclusions

In the present study, the effect of lubrication and nano-reinforcement on the Fretting Fatigue (FF) lifetime and the

fracture behavior of aluminum alloys had been studied.

Obtained results could be listed as follows:

The fatigue lifetime of the samples with nano-particles under the conditions of adding lubricant, at a force level of 15 N, has decreased by 1.6 times, compared to the sample without nano-particles. This value was 1.5 times with decreasing the force level to 10 N.

While increasing the fretting force to 15 N, the fatigue lifetime increased 50 times.

The fatigue lifetime of the sample with nano-particles reduced 1.6 times compared to the sample without nano-particles at the force level of 15 N with the lubricant.

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