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REDUCING ABRASIVE WEAR OF CARBON STEEL BY PLASIC DEFORMATION AFTER UPSETTING

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ABSTRACT

The scratch test was performed to measure the abrasion wear resistance of carbon steel after upsetting at different deformation velocity. In addition, the deformation effect during upsetting was discussed on the frictional behavior involved during the scratching to get a better insight into the wear abrasive resistance of steel after deformation process occurred. The study of scratch formation will be combined with an analysis of the friction of the tested material. The friction coefficient observed by the scratched of carbon steel showed decreasing trend with increasing deformation velocity. The variation of friction is highly evidenced at relatively higher loads. It can be observed that, the scratching causes further strain hardening superimposed on that displayed by upsetting deformation. The decrease of values of friction is related to the hardness increase of the tested material. Increasing the deformation by compression showed lower values of friction coefficients. The dependency of the friction coefficient on the applied load is clearly observed at the lowest deformation velocity. Wear of the tested steel decreases with increasing deformation. As the load increases, wear increases. At the high deformation velocity shows no effect on wear. The effect of deformation velocity on wear is more pronounced than friction coefficient. This behavior can be interpreted considering that wear depends on the depth of stylus tip penetration inside the deformed surface. The hardness of the material increases results the penetration depth decreases. Therefore, at the highest deformation speed wear records the lowest values as a result of the relatively higher values of strain hardening of the deformed steel. The abrasive wear of the metallic material surfaces can be reduced by the plastic deformation process.

KEYWORDS

Surface abrasive wear, scratch test, plastic deformation, carbon steel, deformation velocity

INTRODUCTION

Severe plastic deformation technique can be used to obtain the ultrafine-grained microstructures within the submicrometer and nanometer ranges. Repetitive upsetting extrusion (RUE) is commonly used to induce grain refinement by strain localization. The

process aims to improve the mechanical properties, [1 - 6]. It was indicated that the microstructure can be refined as well due to dynamic recrystallization. The mechanical properties are enhanced significantly due to the decrease in grain size. Surface defects are accompanied to with cold upsetting do not act as stress raisers. Under high plastic deformation, refinement of the microstructure up to sub-microcrystalline (SMC) and even nano-crystalline (NC) grain sizes can possibly change the structure of a metal, [7, 8]. It is well known that materials with SMC structure have relatively higher strength and fatigue resistance at room temperature.

Equal channel angle pressing, (ECAP), can improve the mechanical properties more than three times over the heat treatment condition, [9]. It was found that both Vickers hardness and yield strength significantly increase with ECAP due to the buildup of high dislocation density, which reduces the slip length possibly to a nano-scale.

The mechanism of scratching was divided into two different types. The first one was termed as mild scratching for tough materials, while the second type, termed as severe scratching, for materials of relatively low toughness, [10]. Modeling by the finite element method (FEM) of the scratch test was introduced, [11]. A linear relation between the applied forces, the scratch width and the scratch depth was introduced, [12, 13]. It was shown that the proposed approach provided a method to have specific information of the fracture toughness. Over a wide range of experimental conditions the Co Cr alloy showed significantly better wear resistance. Scratch test is used to evaluate the material wear resistance. Researches performed using scratch tests illustrated the strength properties and fracture properties of metallic and polymeric surfaces, [14 – 18]. Scratch test is a tool for measuring material hardness.

In the present research, the effects of deformation as well as the deformation velocity of carbon steel on the abrasive wear resistance and friction coefficient of were investigated.

EXPERIMENTAL

The test specimens of carbon steel in the form of bars of rectangular cross section of 10 × 10 mm and 20 mm height were tested. The test specimens were compressed by upsetting at 2, 4, 6 and 8 mm axial deformation. The scratch test was carried out by the test rig shown in Fig. 1. The test rig consists of rigid stylus indentor with apex angle 90 degree and the other one hemispherical tip were used. The indentor was mounted to the loading lever through three jaw chuck. A counter weight was used to balance the loading lever before test beginning. Vertical action loading from 2 to 10 N in steps of 2 N was applied. Scratch resistance force was measured by using load cell mounted to the loading lever that connected to display digital monitor. The test specimen was held in the specimen holder which mounted in a horizontal base with a manual driving mechanism to move specimen in a straight direction toward the indenter. The specimens were scratched by an indenter under dry conditions at room temperature.

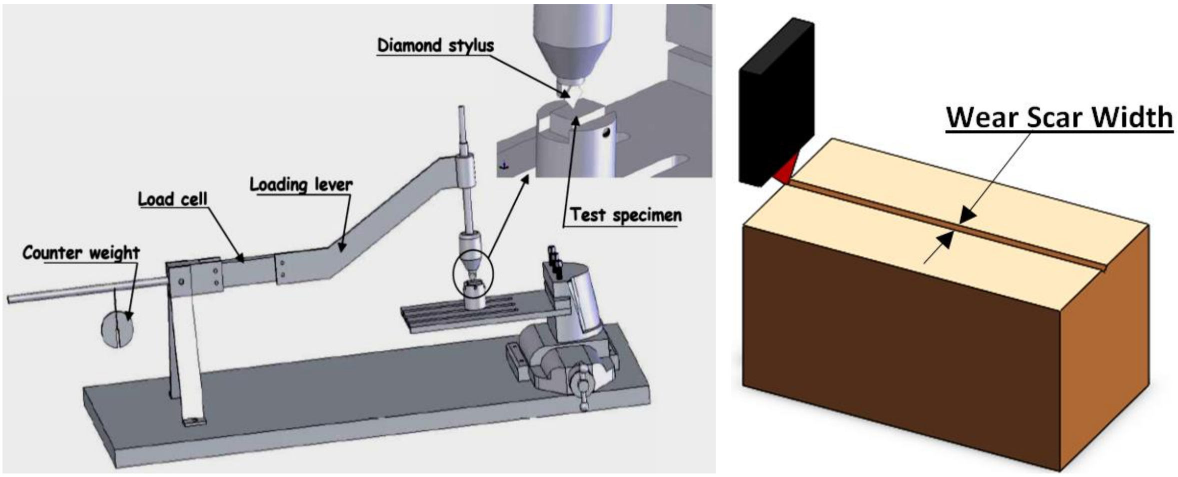

Fig. 1: Arrangement of scratch test rig.

RESULTS AND DISCUSSION

The results of friction coefficient (μ) carried out in the present work are discussed. The scratch test is performed to measure the abrasion wear resistance of carbon steel after upsetting at different deformation velocity. Besides, the deformation effect during upsetting is discussed in the friction process involved during the scratching to get a better insight into the mechanical properties of the work-piece after deformation. The study of scratch formation will be combined with an analysis of the friction values of the tested material. Friction coefficient calculated after the scratch of steel bar after 2.0 mm deformation, Fig. 2, showed a decreased trend with increasing deformation speed. The relative friction decrease is highly pronounced at relatively higher loads. At 2.0 N, μ showed a lower steeper trend with further deformation velocity increase as a result of the relative lower strain hardening of tested steel. It seems that the scratch process causes further strain hardening superimposed on that displayed by upsetting. The decrease of values of μ is related to the hardness increase of the carbon steel. Increasing the deformation of compression to 4.0 mm showed lower values of μexerted by the stylus, Fig. 3. The dependency of μ on the applied load is clearly illustrated at the lowest deformation velocity (2mm/min). Friction decrease may be influenced by the increase of the hardness of carbon steel with increasing the deformation velocity. As the scratched material hardness increases the depth of the stylus decreases and consequently the material removed by scratch decreases causing lower values of friction force. To confirm the dependency of the hardness on the plastic deformation, the relation between them at different values of the deformation velocity is shown in Fig. 4, where hardness proportionally increases with increasing the deformation after compression test. Further increase of the deformation of 6.0 and 8.0 mm showed slight decrease in friction coefficient, Figs. 5 and 6 respectively. At 6.0 mm deformation, friction values are 0.16, 0.18, 0.11, 0.115 and 0.12 at 2, 4, 6, 8 and 10 N load respectively, while at 8.0 mm deformation those values record slight increase. It seems that the tested material does not respond to the relatively higher stress.

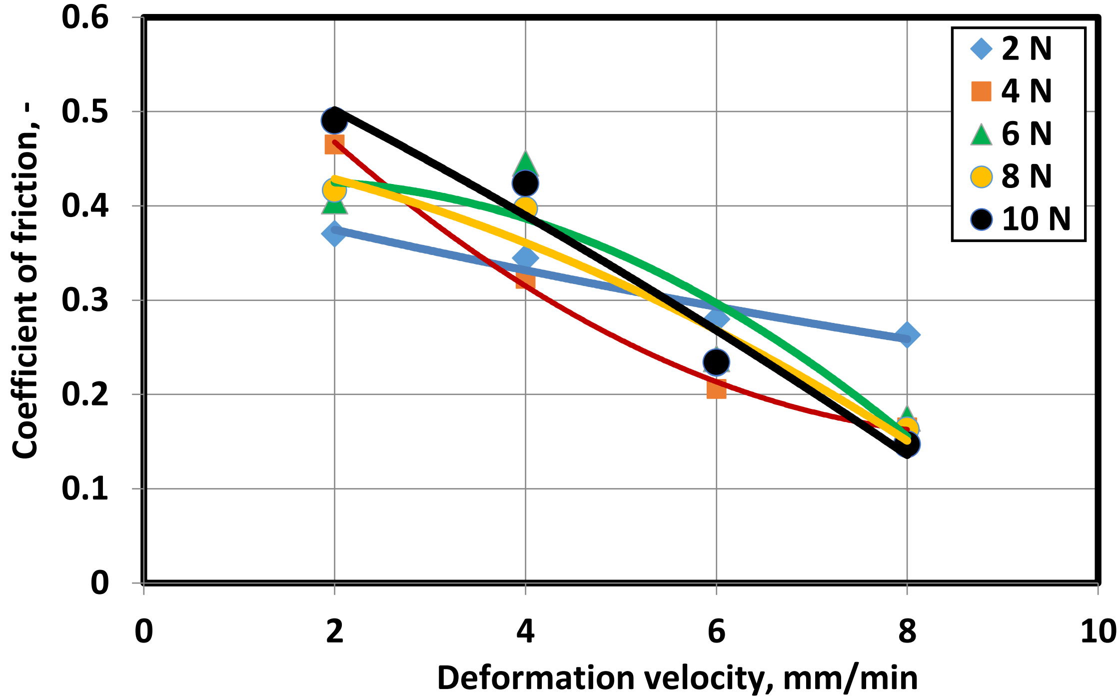

Fig. 2 Friction coefficient displayed by the scratch of steel bar after 2.0 mm deformation.

Wear of was measured by wear scar width shown in Figs. 7 - 10. Wear of testing specimen surface after 2.0 mm deformation drastically decreases with increasing deformation velocity, Fig. 7. As the load increase, wear increases. At the highest deformation velocity load shows no effect on wear. The effect of deformation velocity on wear is more pronounced than friction coefficient. This behavior may be from that wear depends on the stylus tip penetration on the surface. As the hardness increases the depth decreases. Therefore, at the highest deformation velocity wear records the lowest values as a result of the relatively higher values of strain hardening of testing material. This observation recommends the plastic deformation of the surface to enhance abrasive wear resistance. Abrasive wear results of steel surface after 4.0 mm deformation is illustrated in Fig. 8. Wear scar width observed values of 0.078, 0.078, 0.096, 0.108, 0.123 and 0.048, 0.062, 0.072, 0.080, 0.084 at load of 2, 4, 6, 8, and 10 were recorded respectively. The influence of the load is clearly noticed. The lowest wear values are observed at the highest deformation speed. Further wear decrease is observed when the deformation is increased to 6 and 8 mm, Figs. 9 and 10. Abrasive wear is significantly influenced by the load and deformation speed. The lowest wear at 8 mm/min deformation velocity are 0.02, 0.037, 0.061, 0.075 and 0.078 mm, while the values at 8.0 mm deformation are 0.028, 0.035, 0.061, 0.078 and 0.09 mm at 2, 4, 6, 8 and 10 N load respectively.

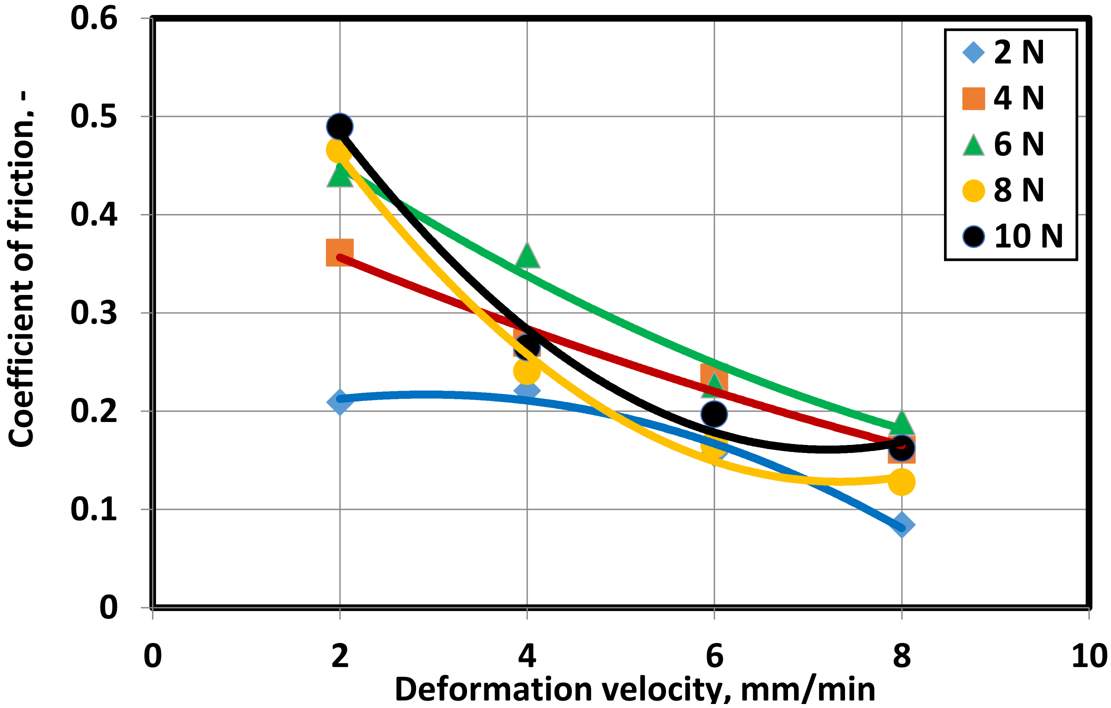

Fig. 3 Friction coefficient displayed by the scratch of steel bar after 4.0 mm deformation.

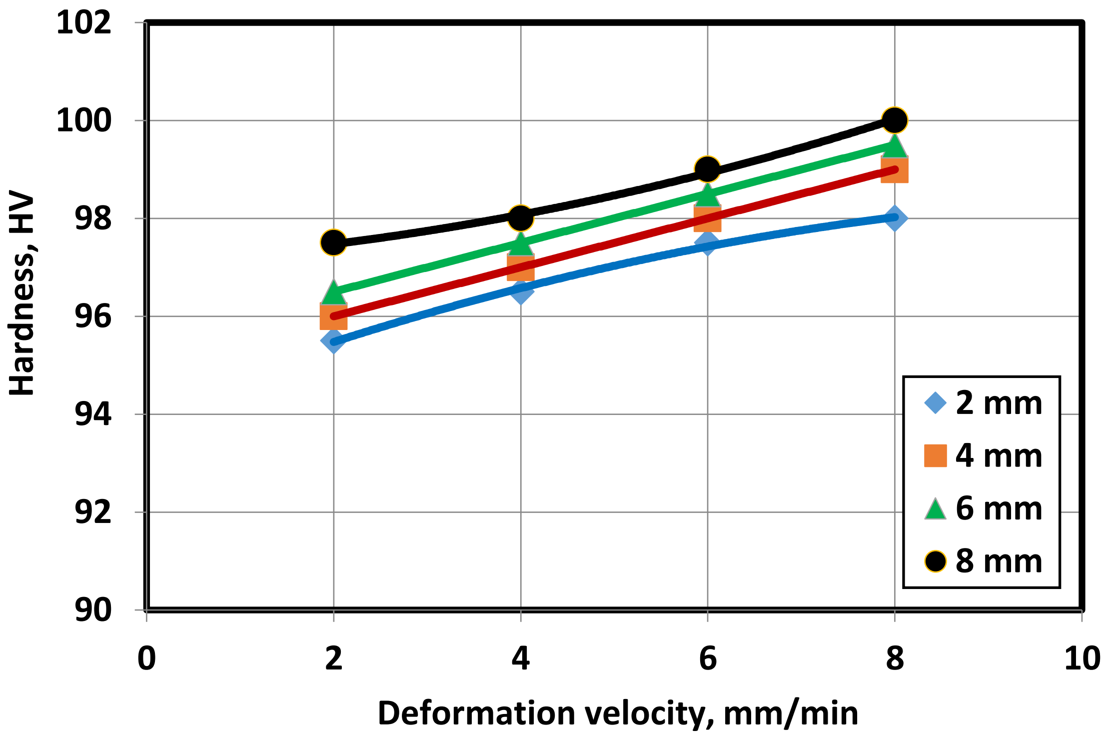

Fig. 4 Relationship between hardness and deformation at different values of deformation velocity.

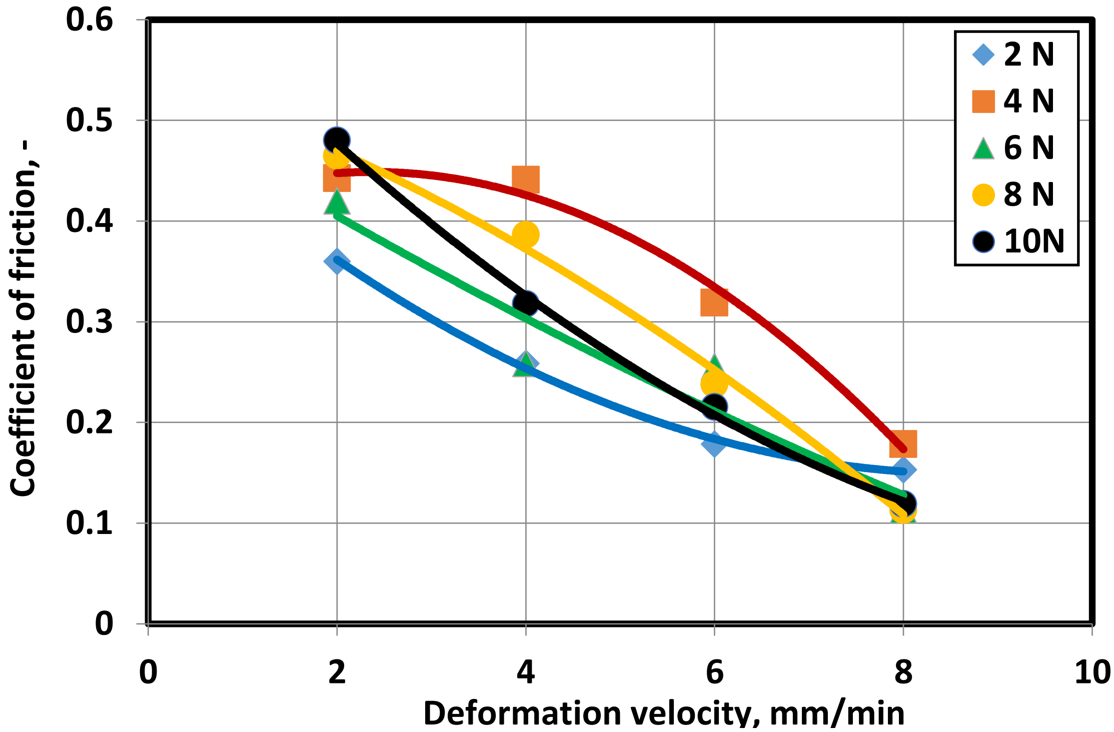

Fig. 5 Friction coefficient displayed by the scratch of steel bar after 6.0 mm deformation.

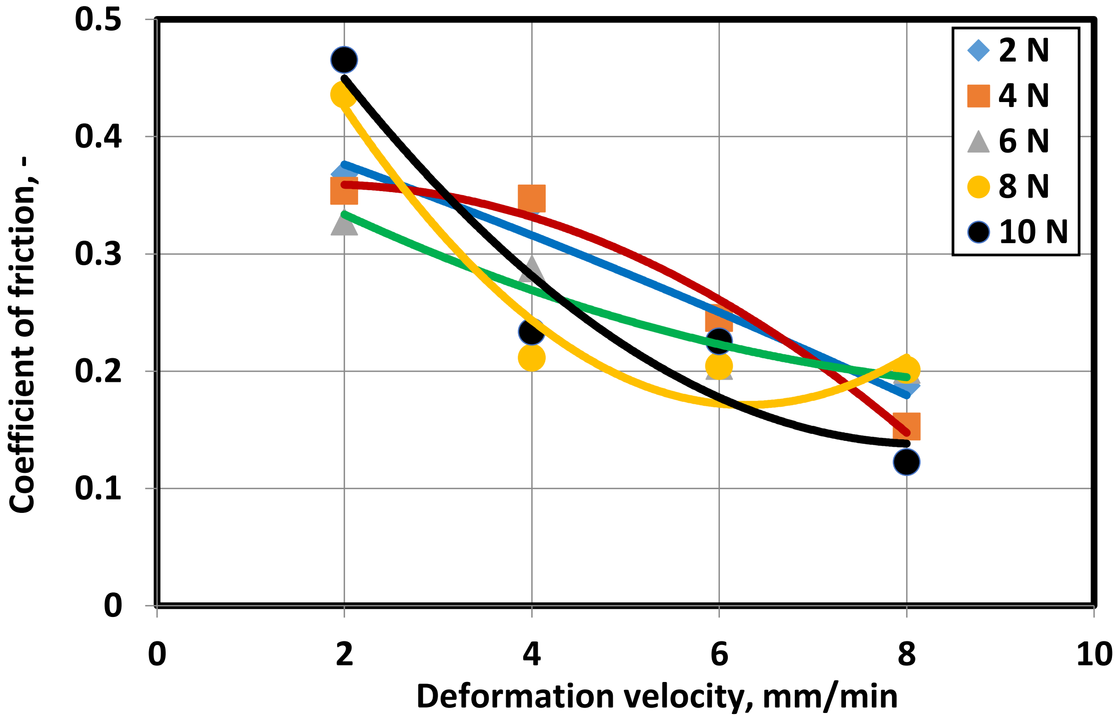

Fig. 6 Friction coefficient displayed by the scratch of steel bar after 8.0 mm deformation.

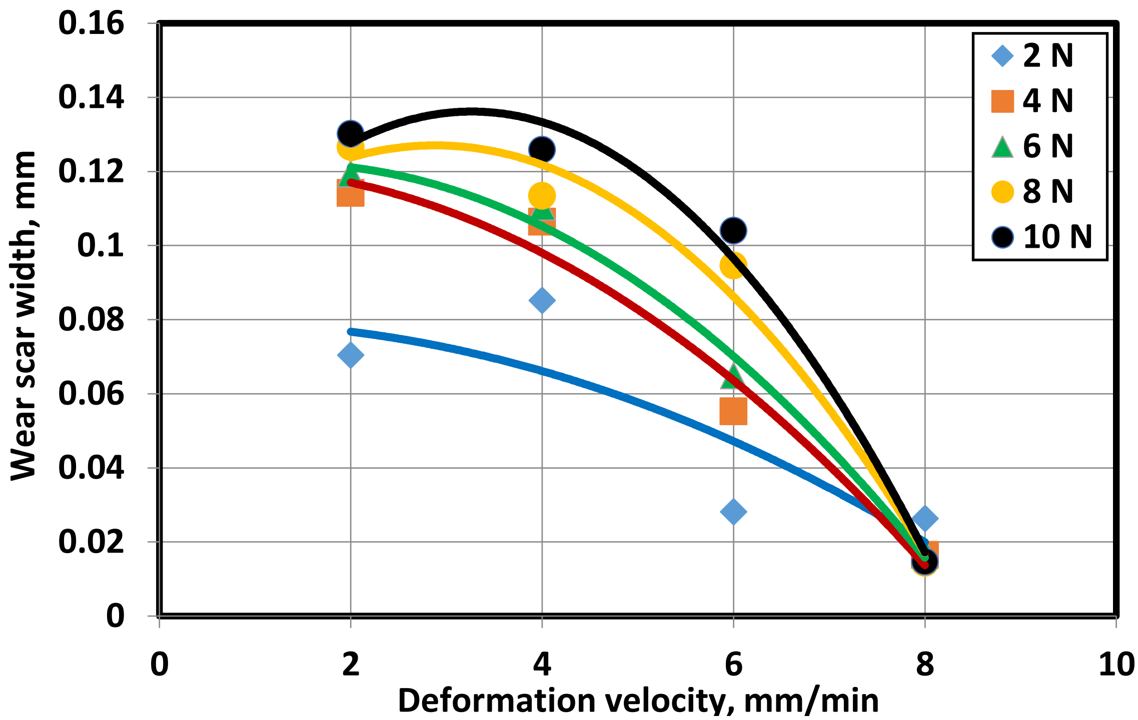

Fig. 7 Wear of steel surface after 2.0 mm deformation.

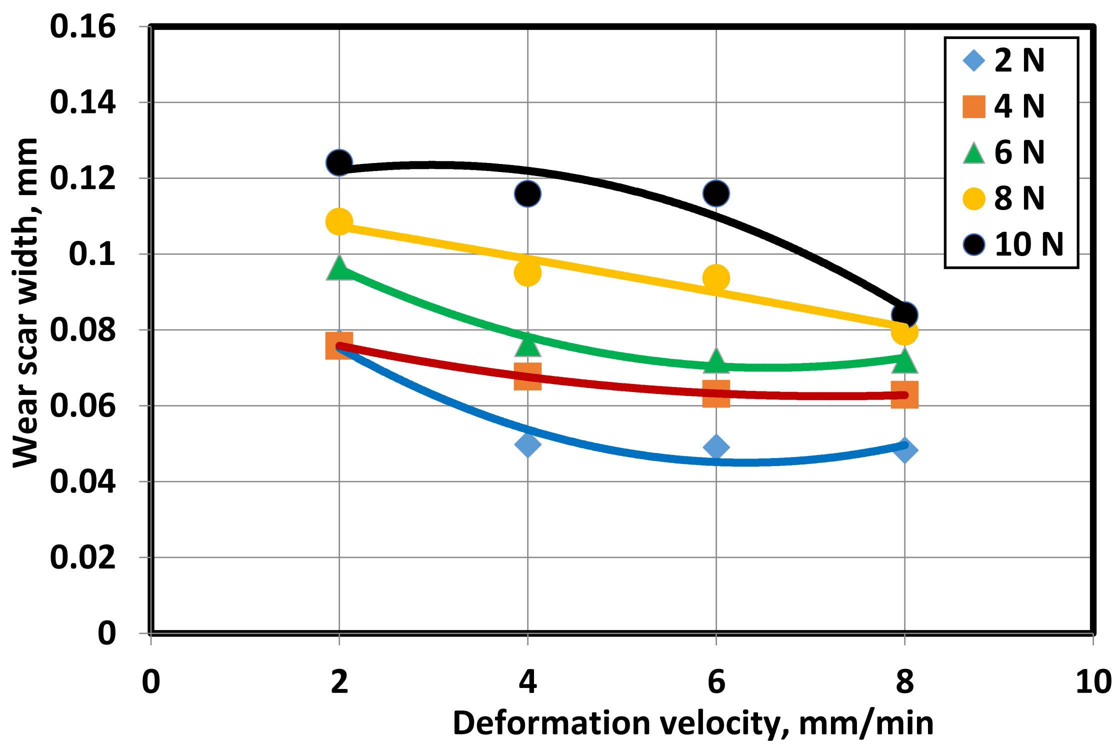

Fig. 8 Wear of steel surface after 4.0 mm deformation.

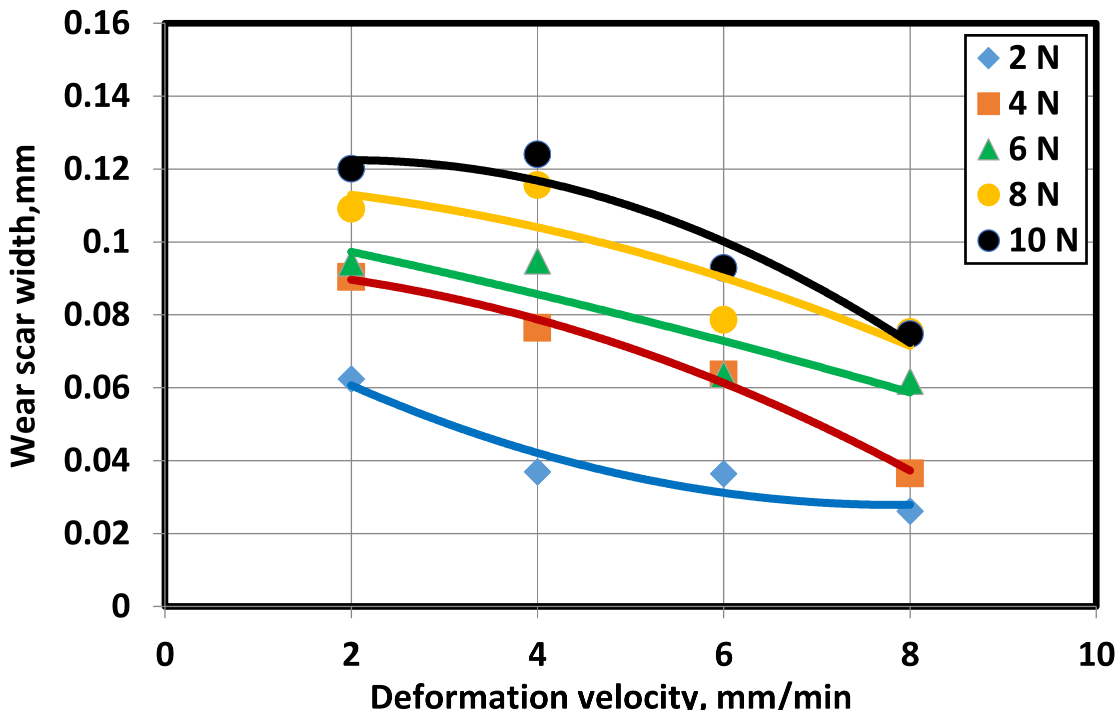

Fig. 9 Wear of steel surface after 6.0 mm deformation.

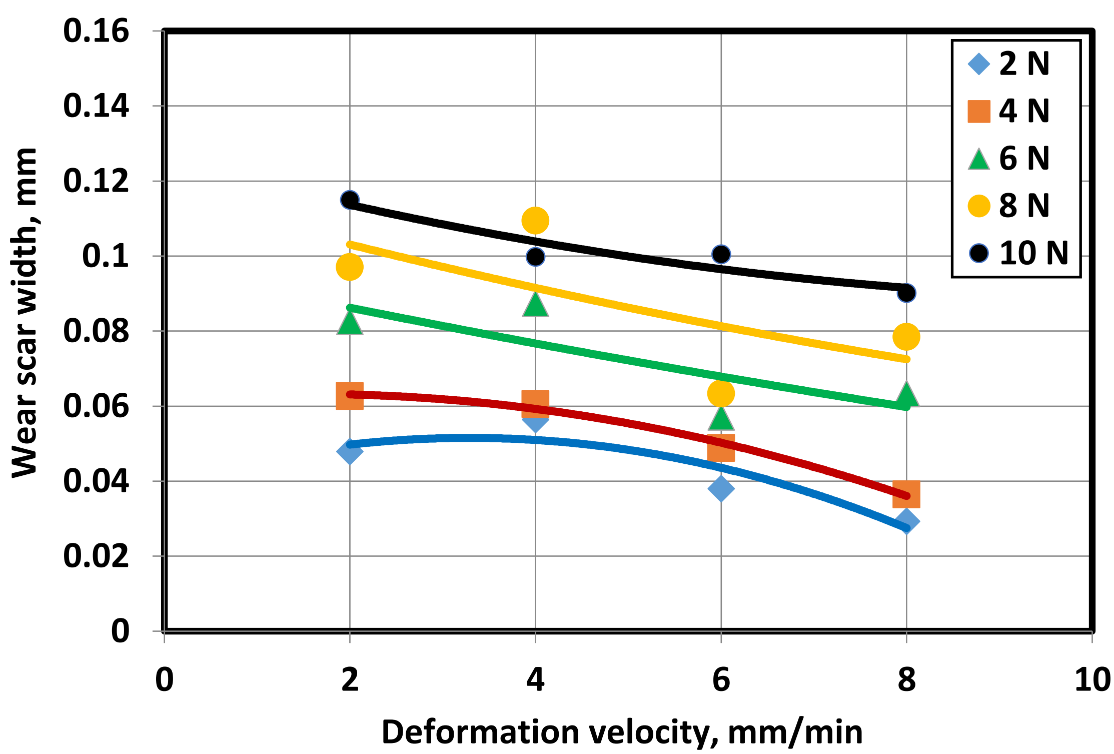

Fig. 10 Wear of steel surface after 8.0 mm deformation.

CONCLUSIONS

1. Friction coefficient displayed by the plastically deformed steel showed decreasing trend with increasing deformation velocity. The relative friction decrease in is highly pronounced at relatively higher loads. Increasing the deformation of compression showed lower values of friction coefficient. The dependency of the friction coefficient on the applied load is clearly noticed at the lowest deformation velocity. Further increase of the deformation showed slight decrease in friction coefficient.

2. Wear drastically decreases with increasing deformation velocity. As the load increases, wear increases. At the highest deformation velocity load shows no effect on wear. The effect of deformation velocity on wear is more pronounced than friction coefficient. This observation recommends the plastic deformation of the surface to enhance abrasive wear resistance. The influence of the load is clearly noticed. The lowest wear values are observed at the highest deformation speed. Wear is strongly influenced by the load and deformation velocity.

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