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ABRASIVE WEAR RESISTANCE OF PLASTICALY DEFORMED CARBON STEEL

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ABSTRACT
The scratch test is performed to measure the abrasion wear resistance of carbon steel after upsetting at different strain rate. Besides, the deformation effect during upsetting is discussed on the friction process involved during the scratching in order to get a better insight into the abrasive wear resistance of carbon steel after deformation. The study of scratch formation will be combined with an analysis of the friction values of the tested material.

It was found that friction coefficient displayed by the scratched steel showed decreasing trend with increasing strain rate. The relative decrease in friction is highly pronounced at relatively higher loads. It can be concluded that scratching causes further strain hardening superimposed on that displayed by upsetting. The decrease of values of friction coefficient is related to the hardness increase of the carbon steel. Increasing the deformation of compression showed lower values of friction coefficient. The dependency of the friction coefficient on the applied load is clearly illustrated at the lowest strain rate. Wear of the tested material drastically decreases with increasing strain rate. As the load increases, wear increases. At the highest strain rate load shows no effect on wear. The effect of strain rate on wear is more pronounced than friction coefficient. This behavior can be explained on the basis that wear depends on the depth of stylus tip penetration in the surface. As the hardness of the material increases the depth decreases. Therefore, at the highest strain rate wear records the lowest values due to the relative higher values of strain hardening. This observation recommends the process of plastic deformation of surfaces to enhance abrasive wear resistance.

KEYWORDS
Abrasive wear, scratch, plastic deformation, carbon steel.

INTRODUCTION
Severe plastic deformation has found a great interest to produce ultrafine-grained microstructures, within the submicrometer and nanometer ranges. Repetitive upsetting extrusion is common 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 well due to dynamic recrystallization. The mechanical properties are improved significantly after RUE processing, which is attributed to the decrease in grain size. Surface defects accompanied to cold upsetting do not act as stress raisers. Refinement of the microstructure up to submicrocrystalline (SMC) and even nanocrystalline (NC) grain sizes grain sizes can possibly change the structure and physical and mechanical properties of a metal under high plastic deformation, [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 enhance mechanical properties more than three times over the annealed 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 nanoscale.

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]. A numerical approach for modeling the scratch test (from a mechanical point of view) using the finite element method was introduced, [11]. A linear relation between the applied forces, the scratch width and the scratch depth was introduced, [12]. It was shown that the proposed approach provided a convenient way to determine the fracture toughness from scratch tests carried out with different scratch widths and depths. Nano-scratch and nano-fretting tests were performed on highly polished biomedical grade Ti6Al4V, 316L stainless steel and Co Cr alloy samples using a 3.7 µm sphero-conical diamond indenter in a commercial nanomechanical test system (NanoTest), [13]. 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 for metallic and polymeric surfaces, [14 – 18]. Scratch test is a tool for measuring material hardness, where hardness is the ability of material to resist abrasion by harder materials.

The present work studies the effect of deformation as well as the strain rate of carbon steel on the abrasive wear resistance.

EXPERIMENTAL

The test specimens of carbon steel in 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, 8 mm axial deformation. The scratch test was carried out by the test rig shown in Fig. 1. It consists of rigid stylus mount, where a steel stylus of 90º apex angle and hemispherical tip. The stylus was mounted to the loading lever through three jaw chuck. A counter weight was used to balance the loading lever before loading. Vertical load was applied by weight of 2, 4, 6, 8 and 10 N. Scratch resistance force was measured using a load cell mounted to the loading lever and 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. The test specimens

were scratched by an indenter. The test was conducted under dry conditions at room temperature.

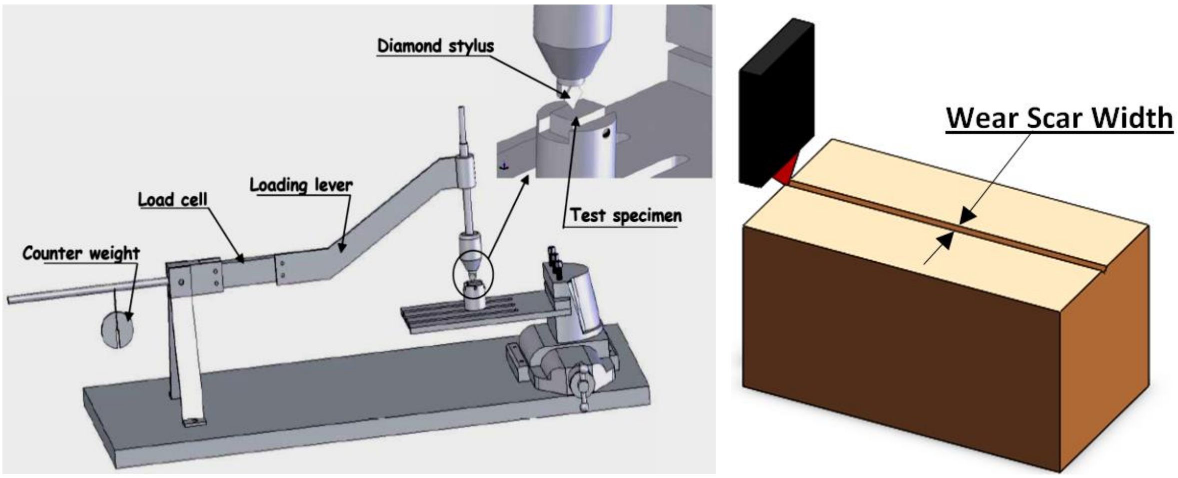

Fig. 1 Arrangement of scratch test rig.

RESULTS AND DISCUSSION

The results of friction coefficient 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 strain rate. Besides, the deformation effect during upsetting is discussed on the friction process involved during the scratching in order to get a better insight into the mechanical properties of the steel after deformation. The study of scratch formation will be combined with an analysis of the friction values of the tested material. Friction coefficient displayed by the scratch of steel bar after 2.0 mm deformation, Fig. 2, showed decreasing trend with increasing strain rate. The relative decrease in friction is highly pronounced at relatively higher loads. At 2.0 N, friction coefficient showed lower steeper trend with further strain rate increase due to the relative lower strain hardening of steel. It seems that scratch process causes further strain hardening superimposed on that displayed by upsetting. The decrease of values of friction coefficient is related to the hardness increase of the carbon steel.

Increasing the deformation of compression to 4.0 mm showed lower values of friction coefficient exerted by the stylus, Fig. 3. The dependency of the friction coefficient on the applied load is clearly illustrated at the lowest strain rate (20 mm/min). Friction decrease may be attributed to increase of the hardness of carbon steel with increasing the strain rate. As the hardness of the scratched material increases the penetration 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 of the tested material on the plastic deformation, the relationship between hardness and deformation at different values of

the strain rate has been plotted in Fig. 4, where hardness proportionally increases with increasing the deformation of the tested material after compression test.

Further increase of the deformation to 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.

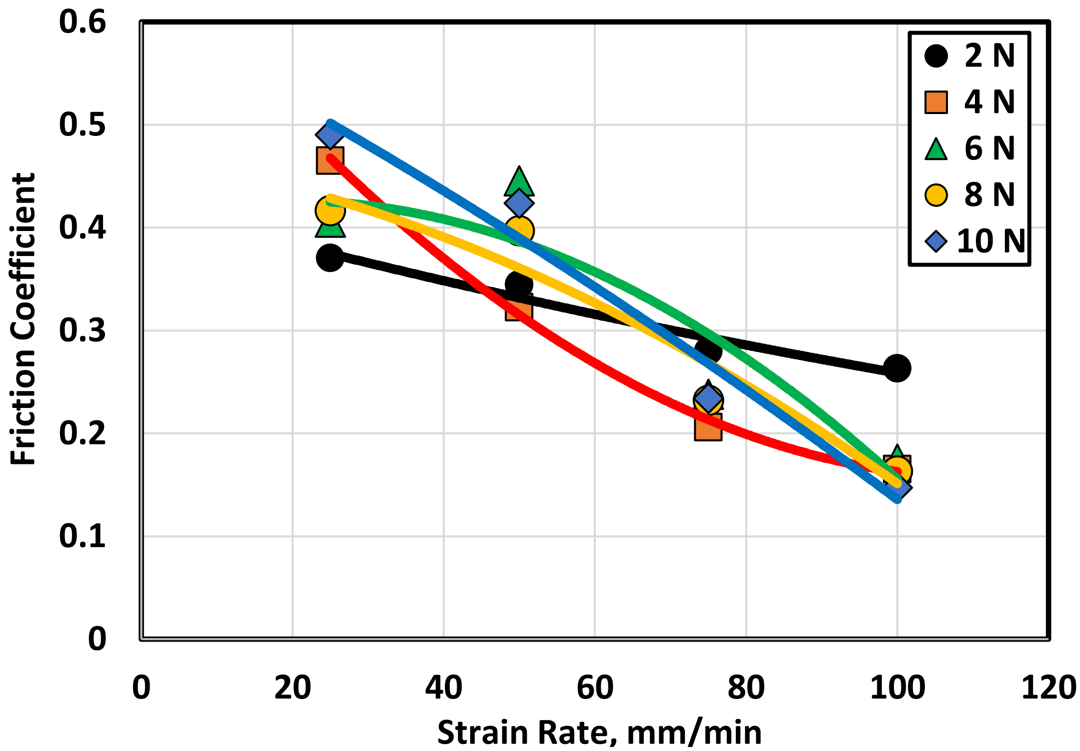

Fig. 2 Friction coefficient displayed by the scratch of steel bar after 2.0 mm deformation.

Wear of the tested material, measured in wear scar width, is presented in Figs. 7 – 0. Wear of steel surface after 2.0 mm deformation drastically decreases with increasing strain rate, Fig. 7. As the load increases, wear increases. At the highest strain rate load shows no effect on wear. The effect of strain rate on wear is more pronounced than friction coefficient. This behavior can be explained on the basis that wear depends on the depth of stylus tip penetration in the surface. As the hardness of the material increases the depth decreases. Therefore, at the highest strain rate wear records the lowest values due to the relative higher values of strain hardening. This observation recommends the plastic deformation of the surface to enhance abrasive wear resistance. Wear results of steel surface after 4.0 mm deformation is illustrated in Fig. 8. Wear scar width displayed 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 respectively. The influence of the applied load is clearly noticed. The lowest wear values are observed at the highest strain rate.

Further wear decrease is observed when the deformation is increased to 6 and 8 mm, Figs. 9 and 10. Wear is strongly influenced by the applied load and strain rate. The

lowest wear values at 100 mm/min strain rate 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.

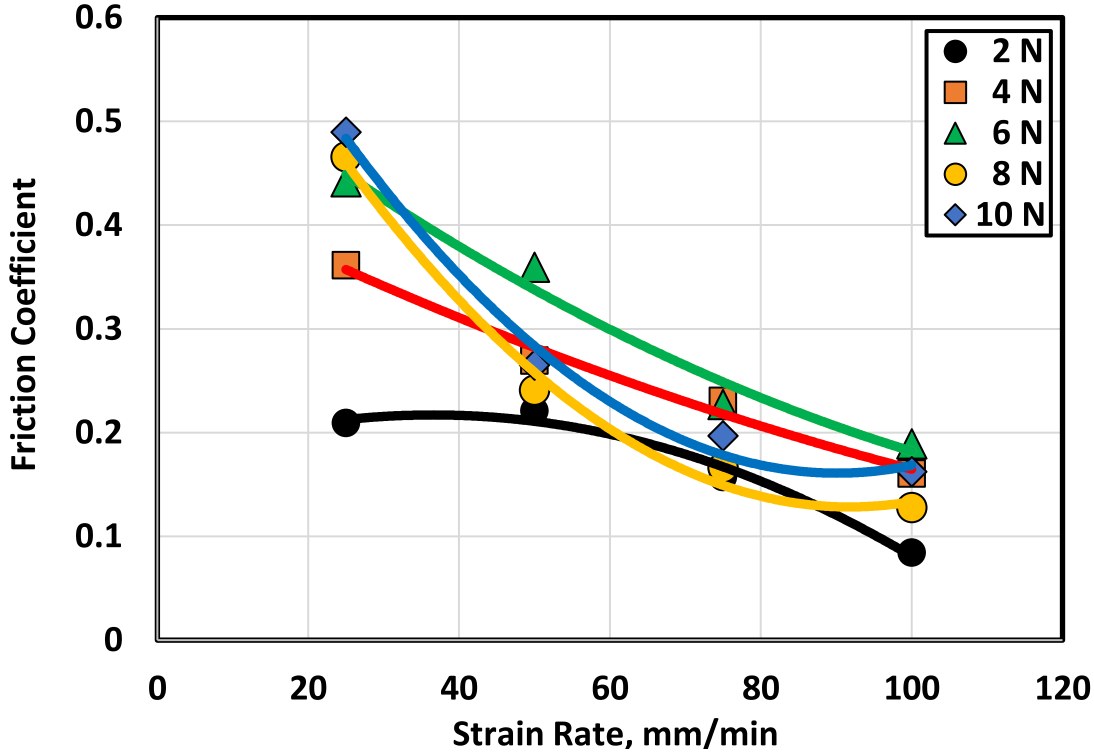

Fig. 3 Friction coefficient displayed by the scratch of steel bar after 4.0 mm deformation.

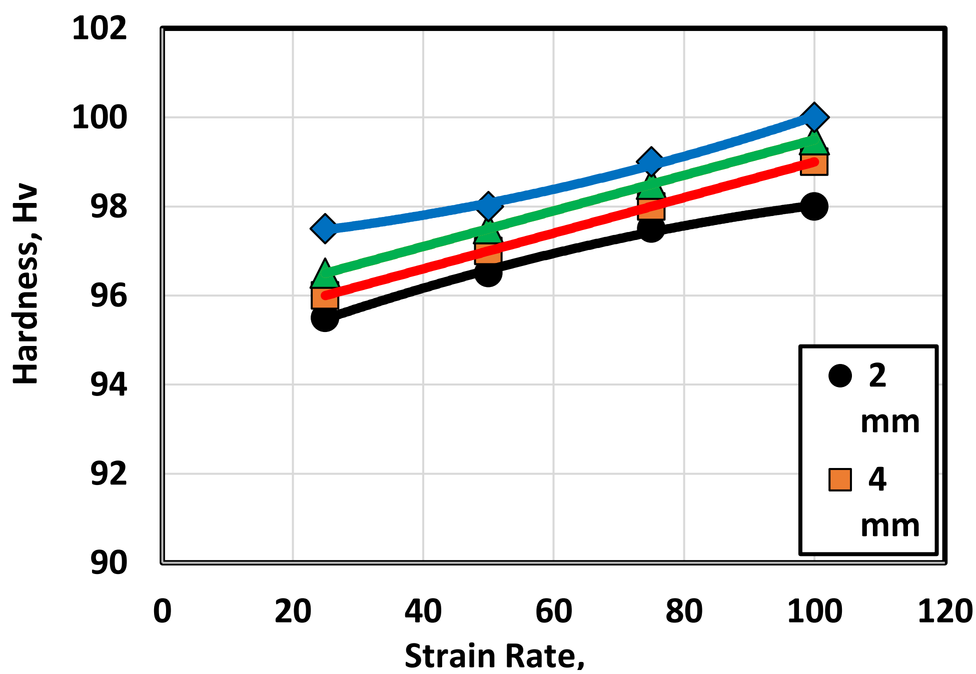

Fig. 4 Relationship between hardness and deformation at different values of strain rate.

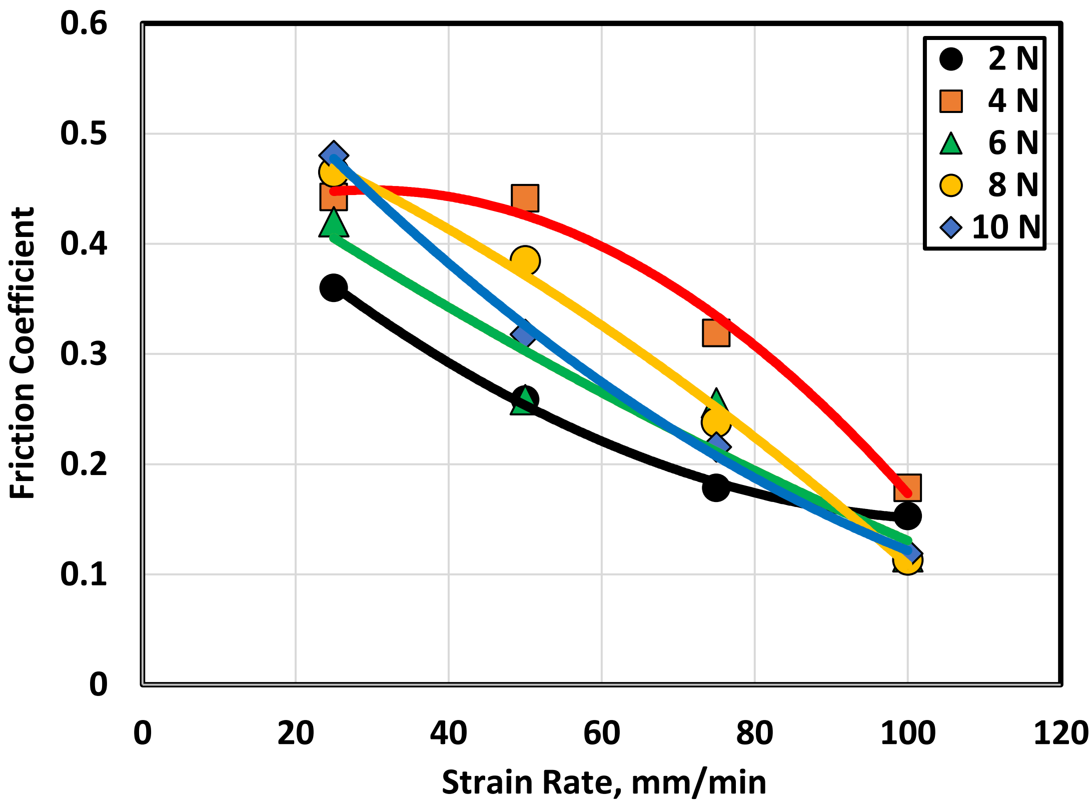

Fig. 5 Friction coefficient displayed by the scratch of steel bar after 6.0 mm deformation.

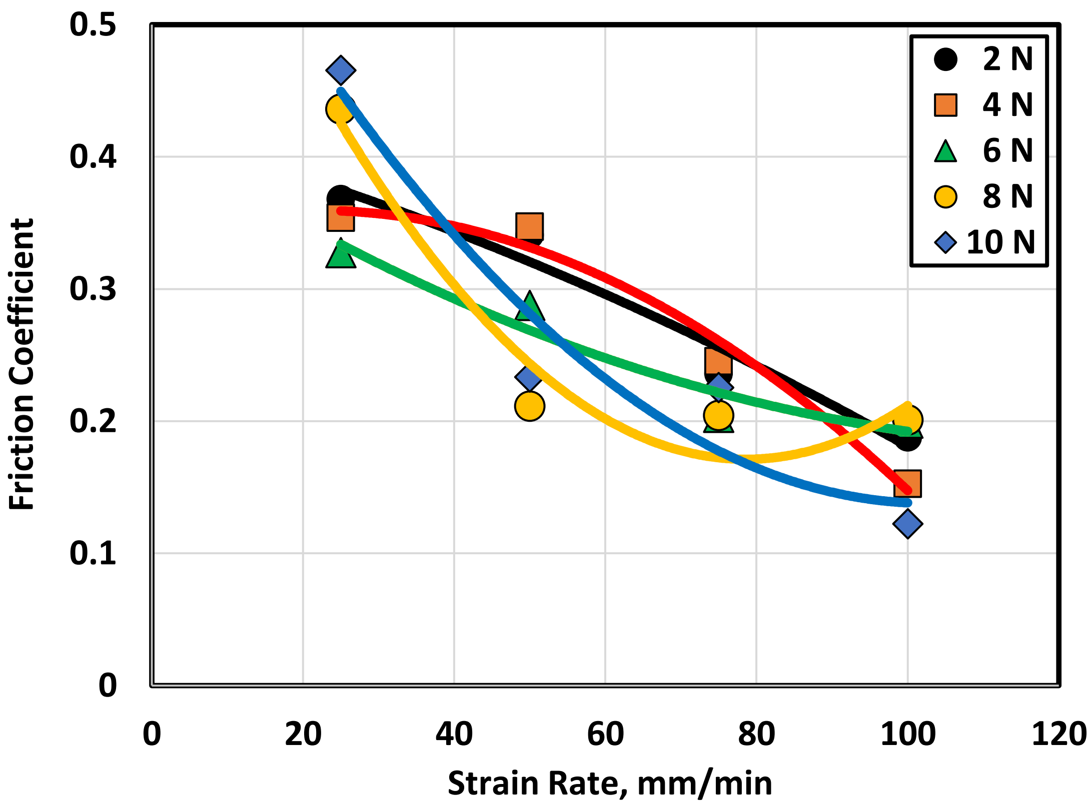

Fig. 6 Friction coefficient displayed by the scratch of steel bar after 8.0 mm deformation.

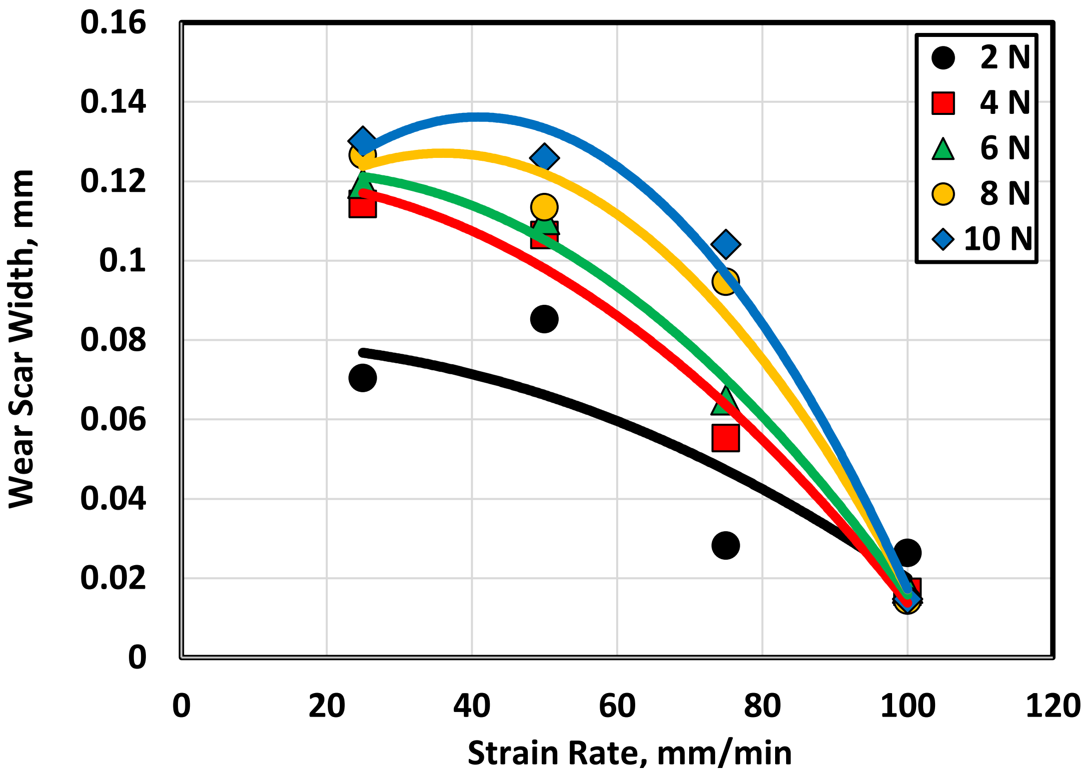

Fig. 7 Wear of steel surface after 2.0 mm deformation.

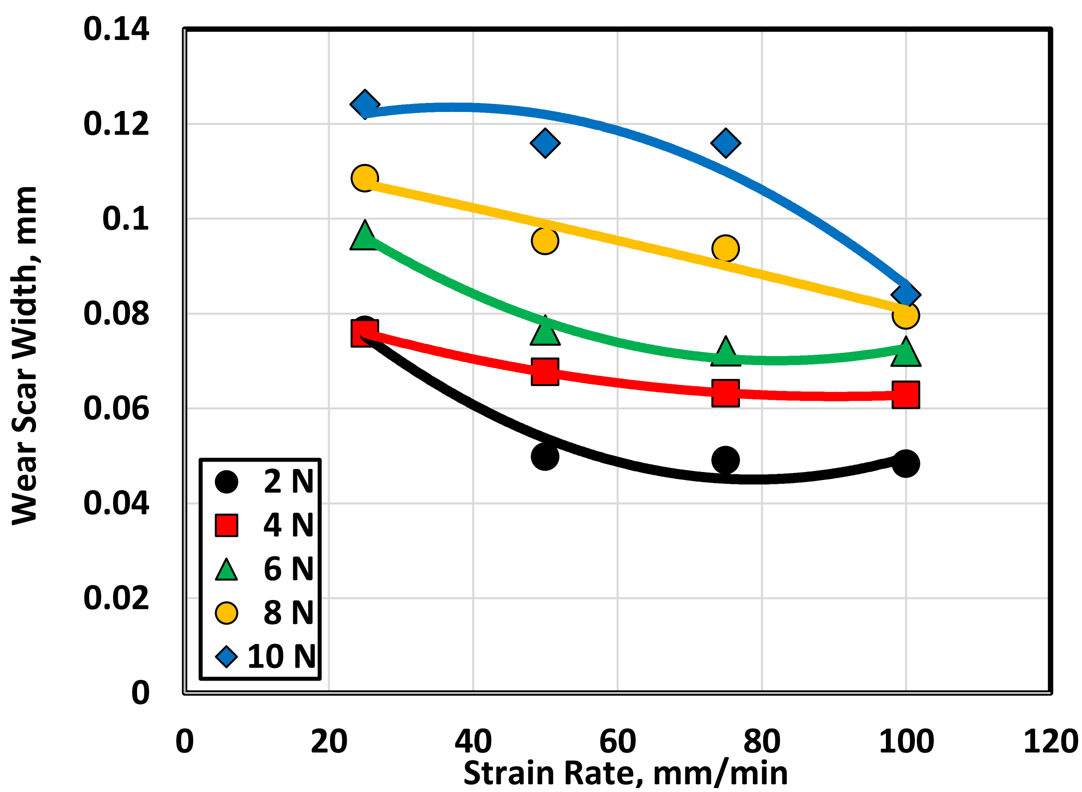

Fig. 8 Wear of steel surface after 4.0 mm deformation.

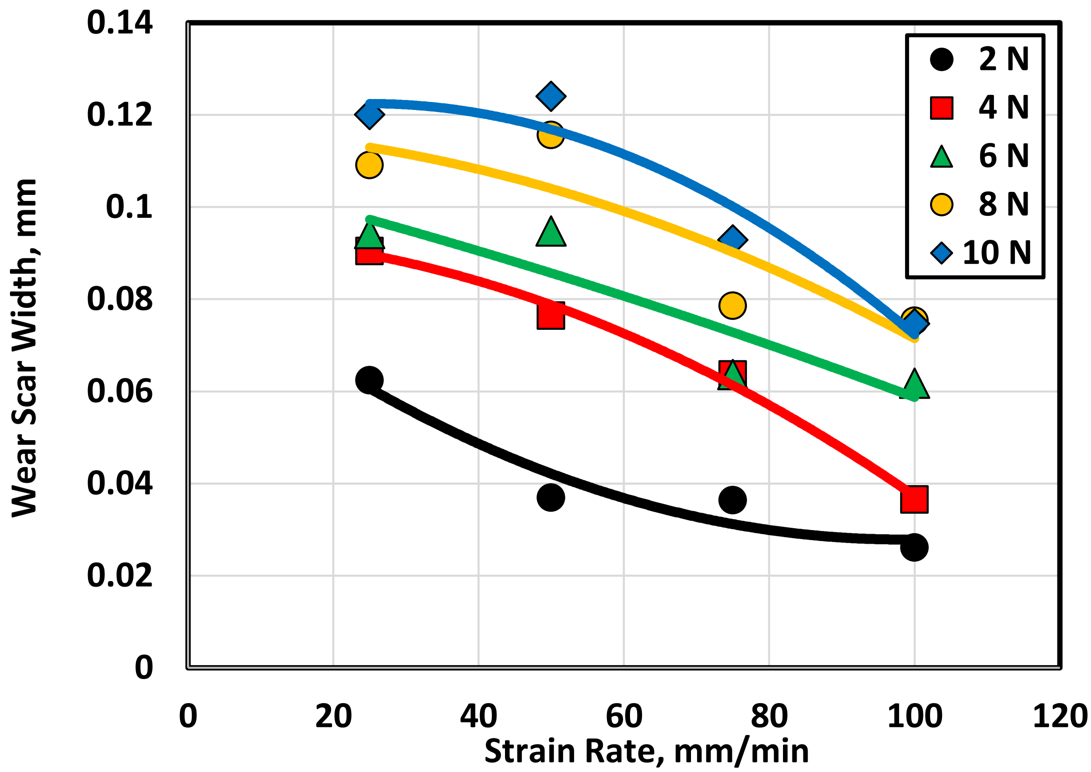

Fig. 9 Wear of steel surface after 6.0 mm deformation.

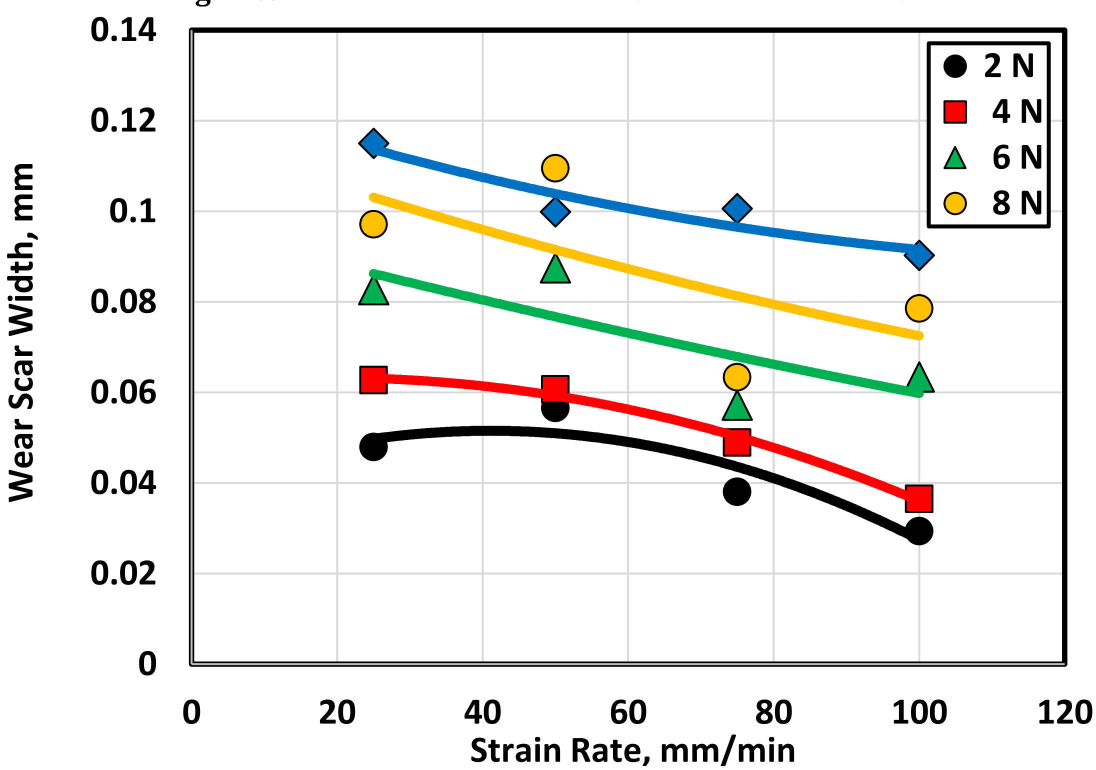

Fig. 10 Wear of steel surface after 8.0 mm deformation.

CONCLUSIONS

1. Friction coefficient displayed by the plastically deformed steel showed decreasing trend with increasing strain rate. The relative decrease in friction 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 strain rate. Further increase of the deformation showed slight decrease in friction coefficient.

2. Wear of the tested material drastically decreases with increasing strain rate. As the load increases, wear increases. At the highest strain rate load shows no effect on wear. The effect of strain rate 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 applied load is clearly noticed. The lowest wear values are observed at the highest strain rate. Wear is strongly influenced by the applied load and strain rate.

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