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# Heat-treatment process and peening intensity on abrasive wear response of agricultural grade boron steel in dry sand and slurry

DUSHYANT SINGH[1] and D P MONDAL[2]

*Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh 462 038*

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## ABSTRACT

The aim of present study is to understand the low stress abrasive wear response of heat-treated and shot peened agricultural grade boron steel under dry and slurry conditions. Heat-treatment (annealing, inter-critical annealing and quenching and tempering) was carried out to alter the mechanical as well microstructural properties of steel. The surface properties were further improved by shot peening carried out at 0.17 A and 0.27 A peening intensities. The wear test methodology adopted in this study is very well simulated with working condition of soil working fast wearing components of agricultural implements like cultivator sweeps, furrow opener of seed drills and plough share etc. The study reveals that the heat-treatment and shot peening together improve the abrasive wear resistance of boron steel significantly in dry condition but heat-treatment does not have any significant effect on abrasive wear resistance in slurry due to the presence of corrosive media, besides shot peening under such circumstances leads to inferior wear resistance. This technique is found promising to improve the quality of soil working agricultural components working in dry condition but not fruitful in slurry condition.

**Key words**: Abrasive wear, Agricultural machines, Dry sand and slurry abrasion, Heat-treatment cycle, Soil working components, Shot peening

In India agricultural machinery like plough, disc harrow, cultivator, seed-drill and puddler are commonly used by farmers for seedbed preparation. Correspondingly the equipment is having share, disc, sweep, furrow opener and lugs. These components are normally made of medium carbon steel and are severely subjected to abrasive wear, impact load and chemical action. Several researchers have reported that the wear rate of soil moving, cutting and threshing equipment is very high (Singh and Saxena 2008 and Singh *et al.* 2009).

Therefore, they require a certain level of mechanical and tribological properties. Presently, boron steels have replaced alloy steels in European countries. Trace boron can enhance the hardenability of steels to a great extent. The applications of boron steels could be agricultural machinery blades, sweeps, points, triangular shovels, chisels, Knife sections, shares and other soil and plant engaging components requiring higher wear resistance and strength. Boron steel exhibits better sliding and abrasive wear resistance than the high carbon steel and when present in small quantity (in ppm level) it provides good combination of strength, hardness, ductility, toughness and fatigue strength due to formation of tempred martensitic microstructure (Singh *et al.* 2008, 2010). A group of researchers found heat-treatment a simple and flexible process to improve the wear resistance for agricultural implements (Singh *et al.* 2008, Modi *et al.* 2007, Modi 2007) and others studied various surface modification techniques like diffusion heat-treatment (Er and Par 2006, Meric *et al.* 2006, Allaoui *et al.* 2006, Bejar and Moreno 2006), hard facing (Harval *et al.* 2008, Bayhan 2006) and coatings (Khan *et al.* 2010) for soil working components of agricultural machinery.

All above surface modification techniques are cost and energy extensive. The shot peening is found to be an appropriate technique to strengthen (improve the strength and hardness) of alloys or metals at lower cost. Shot peening improves surface hardness, strength and wear resistance of all metals if restricted to a certain limit (Mondal *et al.* 2008, Singh *et* al. 2010, Singh *et al.* 2011). Three- body abrasive wear resistance of steel increases by 72% by shot peening (Yan *et al.* 2007). Intermediate peening is required in soil working components after a certain interval (Singh *et al.* 2010). Furthermore, shot peening imposes residual stress on the surfaces, which may facilitate corrosive wear. This makes us suspicious about the effect of shot peening on the slurry

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[1] Scientist (e mail: dsingh@ciae.res.in);

[2] Scientist E-2 (e mail: mondaldp@yahoo.com), Advanced Materials and Processes Research Institute, Bhopal

abrasive wear. In this paper, the synergic effect of heat-treatment processes and peening intensities are examined on abrasive wear behaviour of boron containing medium carbon low alloy steel under dry sand and slurry conditions.

## MATERIALS AND METHODS

The experiment was conducted at Central Institute of Agricultural Engineering, Bhopal during 2009–10 to study the wear response of boron steel used for agricultural machinery. The material used in experiment is 50B50 steel, its weight percentage is 0.50% C, 0.21% Si, 0.78% Mn, 0.95% Cr, 0.005% B and remaining Fe. Three different types of heat treatment (carried out at Indo German tool room, Indore) cycles were carried out in the present investigation as shown in Table 1. The hardness of as received and heat-treated specimens was measured at 30 kgf on Vicker's hardness tester. The microstructure of as-received and heat-treated specimens was examined on polished and etched specimen using Scanning Electron Microscope (SEM) at Advanced Materials and Processes Research Institute, Bhopal as per standard procedure.

The shot peening was carried out on ground (400 grade emery paper) steel specimens at 0.17 A and 0.27 A peening intensities on make shot-peening machine at CIAE, Bhopal. Standard "A" type Almen strips were used to calibrate the peening intensity. The expose time was varied, keeping other parameters constant, for obtaining 0.17 A and 0.27 A peening intensities. The peening intensity is defined as the deflection at the centre of the strip from its original position.

Low stress abrasive wear in dry sand and slurry was measured as per ASTM G 65 standard using DUCOM, Bangalore make rubber wheel abrasion testers (Fig 1). In both the cases, the specimens were polished according to standard metallographic techniques before start the test and subsequent tests were conducted on pre worn surfaces. This process was repeated to obtain steady state value of the wear rate. The specimens were tested at 200 N load and wear rate calculated from the weight loss measurement. This test methodology is very well simulated with the working condition of fast wearing components of agricultural machinery. The test specimen is pressed against a rotating wheel, while a controlled flow of abrasive particles is maintained at the test surface. In case of dry sand abrasion wear, crushed silica sand particles (size: 212–300 mm) at the rate of 370 g/min is applied for abrasive action. During the tests, a sliding speed of 1.86 m/s was maintained. In case of slurry testing the abrasive media is filled in a close chamber in place of falling sand in dry sand abrasion tester. The specimens were tested for same linear sliding distance in the slurry of silica sand and water (1:1.5 ratio).

## RESULTS AND DISCUSSION

### *Material and microstructure*

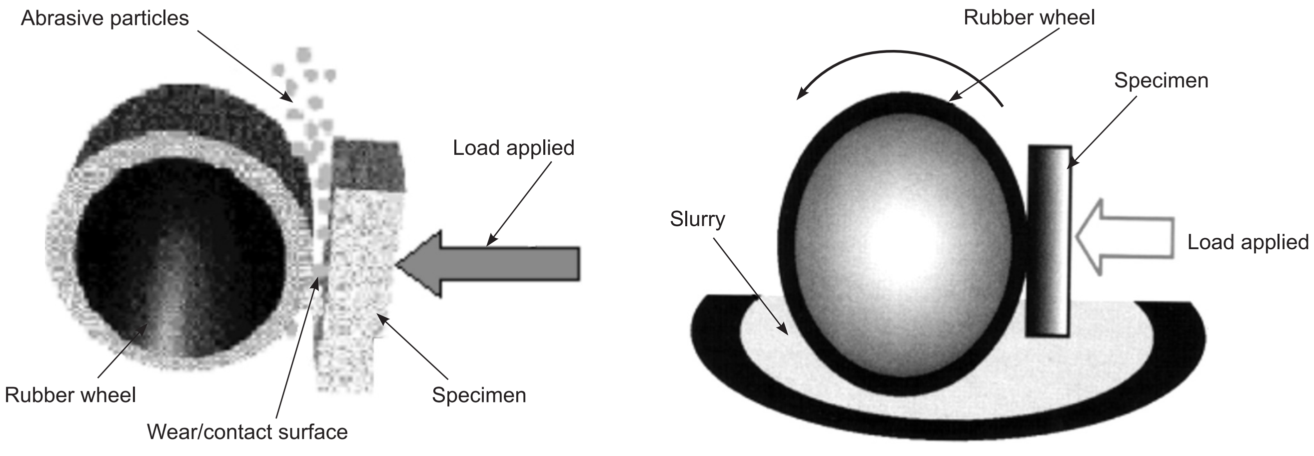
The average hardness and volume fraction of micro constituents of the investigated steel before and after heat-treatment processes is given in Table 1. It is clear from this table that the micro-structure of as received (Near pearlitic structures 85% pearlite and 15 %ferrite) and annealed (Near pearlitic structures 80 % pearlite and 20 % ferrite) steels are almost identical only the percentage of ferrite is increased by about 5 % when the steel under gone annealed process as compared to as-received steel. But the interlaminar spacing is noted to be relatively coarser in case of AN specimen. The ICA steel contains 80% tempered martensite and 20 % ferrite. Whereas, QT condition depicted 95 % tempered martensites with 5% retained austenite. The martensitic structure is relatively harder in comparison to ferritic and pearlitic, so the hardness of the heat-treated specimen increases with increase the martensite content. The hardness of the ICA and QT specimens were found to be more than twice the hardness of AR and AN steels.

### *Effect of sliding distance and heat treatment on abrasive wear*

The wear rate as a function of sliding distance for heat-treated un-peened specimens is depicted in Fig 2 (a, b) for

Table 1 Heat treatment schedules for the steels used for the study

| Name of treatment with code | Heat treatment cycles | | | | | Properties | |
|---|---|---|---|---|---|---|---|
| | Austenising temperature | Socking time (min) | Quenching media | Tempering temperature | Tempering time (min) | Hardness (Hv) | Microstructure |
| As received (AR) | Un-treated | | | | | 180 | Near pearlitic structures 85% pearlite and 15% ferrite |
| Annealing (AN) | 870 °C | 120 | Furnace cooling | | | 170 | 80% pearlite and 20% ferrite |
| Intercritical annealing (ICA) | 870 °C<br>777 °C | 120<br>30 | water with 8% Nacl | 250°C | 120 | 446 | 20% ferrite and 80% martensite |
| Quenching & tempering (QT) | 870 °C | 120 | water 8% Nacl | 250°C | 120 | 458 | 95% tempered martensite and 5% retained austenite |

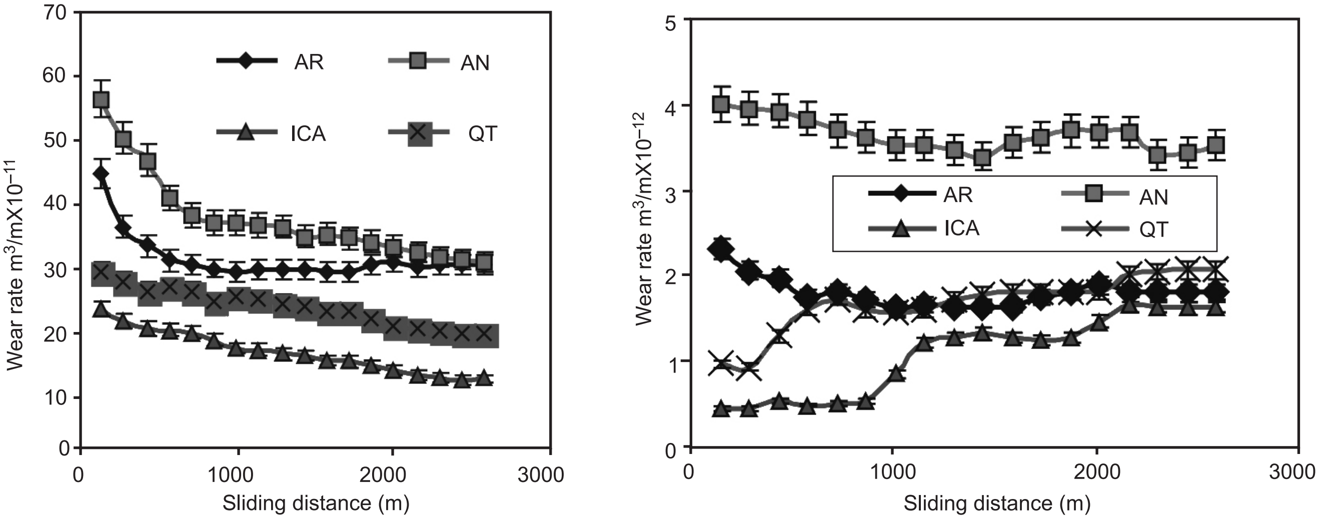


(a) (b)

Fig 1 Schematic out line of low stress abrasive wear in (*a*) dry sand, and (*b*) slurry

dry and slurry abrasion respectively. In case of dry abrasion (Fig 2a) the work hardening due to continuous plastic deformation reduces the wear rate monotonically with sliding distance and the wear rate of AR and AN specimens are almost equal in steady-state condition, although the initial wear rate of AR specimen was lower than the annealed specimen. Whereas, in case of ICA and QT the wear rate are considerably less than that of AN and AR specimens. It is 36 % and 61 % lower in QT and ICA, respectively (Fig 2a) as compared to AR/AN one. ICA specimen shows relatively lesser wear rate (34% approximately) in comparison to QT specimen. The significant reduction in wear rate in ICA and QT treatment could be due to formation of dual phase ferrite and martensite structure or tempered martensitic structure. These structures provide good combination of strength and toughness which are primary requirement to resist the abrasive wear.

In case of slurry abrasion, as shown in Fig 2b, the wear rate of AN and AR specimens is decreasing with sliding distance and finally approaching a steady state value. But, in case of ICA and QT, the wear rate first increases with sliding distance and finally attained a steady state value. Additionally, the wear rate is found to be considerably high in annealed specimens and it is followed by QT, AR and ICA. The wear rate, in case of AN and QT is 96.7% and 15.08% higher than the wear rate of AR specimens respectively. Whereas, in case of ICA specimens, it is 8.4% lower than AR. The wear rate is considerably high in case of AN specimen because of lower hardness of the specimens as compared to others. The decrease in wear rate with sliding distance in AR and AN samples may be due to progressive increase in the surface hardness due to work hardening, decrease in corrosion rate due to formation of passive layer and change in *p*H leads to reduction in corrosion rate.



(a) Dry sand (b) Slurry

Fig 2 Effects of sliding distance and heat treatment on abrasive wear rate of un-peened 50B50 steel at 200 N load in (*a*) dry sand, and (*b*) slurry

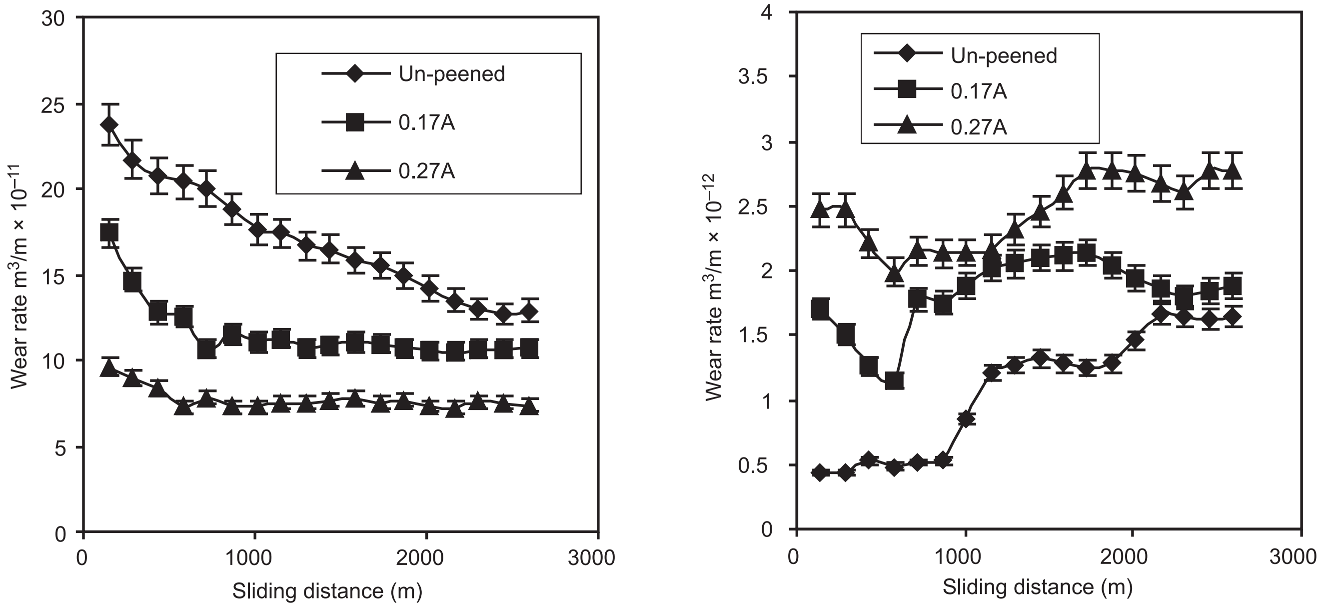
The brittleness of martensitic structure along with higher carbide/ matrix interface due to fine martensite is responsible for more corrosion in QT specimen, which ultimately leads to greater wear rate. Higher corrosion rate in QT and ICA multiplies the work-hardening effect. As a result, the wear rate increases with sliding distance. Above a certain distance the activity of solution gets reduced and a passive layer is formed over specimen. This leads to lowering the extended of wear rate. The hard and tough dual phase specimen ICA exhibits lowest wear rate because of excellent combination of toughness and hardness as compare to QT and other steels.

### *Effect of sliding distance and peening intensity on abrasive wear*

Fig 3(a, b) depict the wear rate as a function of sliding distance for ICA specimen in dry sand and slurry conditions respectively. As discussed earlier in case of un-peened condition, the wear rate decreasing with sliding distance and obtain a steady state value. The wear rate of peened specimen is lower than that of un-peened specimens. The wear rate decreased by 17.12% and 43.14% respectively, when the specimen were peened at 0.17 A and 0.27 A intensities respectively. This reduction in wear is due to improvement the surface hardness, refinement in micro-structure and development of residual compressive stresses at the surface and sub-surface level of the specimen. Fig 3b exhibits the variation of wear rate with sliding distance for ICA specimen in slurry abrasion. The above figure shows that the wear rate for un-peened specimen remains almost invariant up to 864 m sliding distance and than it increases sharply. After that, the wear rate remains constant up to 1 872 m and then again increases rapidly and finally reach a steady state value. In case of ICA specimen peened at 0.17 A and 0.27 A intensities, the wear rate decreases and reaching to minimum value at 576 m and start increasing sharply before attaining a steady state value at 1 728 m. After reaching to minima, the wear rate increases with further increase in sliding distance and finally attaining a steady state value. Decrease in wear rate with sliding distance is attributed to decrease in the fracturing tendency of leaps and flash produced around dents during peening process, whereas, the increase in wear rate is primarily may be due to higher corrosion rate. Peened specimen exhibits higher wear rate because of higher corrosion rate due to existence of higher residual stresses. The wear rate in ICA as well as in QT specimens increases with peening intensity. The behaviour of QT specimens is also noted to be similar to that of ICA specimen. Here also, the peened specimen exhibits higher wear rate than the un-peened sample as discussed earlier.

### *Effect of heat treatment and medium on relative wear resistance*

The relative wear resistance ($R_{WR}$) of steel specimen is defined as the ratio of wears resistance of specific specimen ($W_{RS)}$ to the wear resistance of specimen with respect to which (as received in case of Fig 4a and un-peened heat-treated in case of Fig 4b the behaviour is compared ($W_{RC}$). In Fig 4a the relative wear resistance of un-peened AN, QT and ICA specimen, at 200 N load under slurry and dry conditions are depicted with respect to AR specimen. In slurry condition, the wear resistance of AR, ICA and QT specimens is comparable, but the relative wear resistance of



(a) Dry sand

(b) Slurry

Fig 3 Effect of shot peening on wear behaviour of 50B50 steel at 200 N load in (*a*) dry sand, and (*b*) slurry annealed specimen is quiet low. It is further demonstrated that QT specimen exhibits marginally lower wear resistance as compared to AR. But the ICA exhibits marginally higher wear resistance than AR. The wear resistance reduced to 0.51 and 0.87 times in case of AR and QT as compared to received specimen respectively. But the same increases marginally to 1.09 times in case of ICA.

In case of dry sand abrasion, the relative wear resistance of AN and AR are comparable. The relative wear resistance of AN specimen is marginally low because of low hardness of this specimen. In case of dual phased ICA specimen, the combined effect of hardness and toughness leads to increase in the relative wear resistance of to 2.37 times of AR specimen. But the wear resistance of QT specimen is only 1.55 times of that of AR sample. It is interesting to note that effect of heat treatment leads to different trend in wear resistance in dry and slurry condition. QT exhibits relatively inferior wear resistance as compared to AR in slurry condition attributed to higher corrosion rate (corrosive wear) because of greater residual stresses (quenched specimen) and finally dispersed carbides (which leads to more galvanic corrosion) in case of dry wear condition, hardness and toughness are the governing factors and hence QT and ICA gives improved wear resistance.

### *Effect of shot peening intensity on relative wear resistance*

The effect of peening intensities on relative wear resistance (with respect to un-peened specimen) of ICA and QT specimens in slurry and dry condition is shown in Fig 4b. It is clearly noted from Fig 4b(i) that in slurry condition, the relative wear resistance is decreasing with increasing the peening intensity. In slurry condition, the relative wear resistance of 0.17 A and 0.27 A peened specimen is only 0.87 and 0.59 times of un-peened specimen. But the relative wear resistance in dry condition increases significantly with increase the peening intensity. The relative wear resistance of 0.17 A and 0.27 A peened specimen is increased by 20.65% and 75.58% respectively. This increase in relative wear resistance is due to development of residual compressive stresses (which resist the micro crack propagation) and increase in surface hardness because of work hardening in peening operation (which decrease the depth of penetration). Decrease in wear resistance due to peening in slurry condition is primarily due to greater contribution from corrosion, which has been explained earlier.

Almost similar observations were found in case of QT

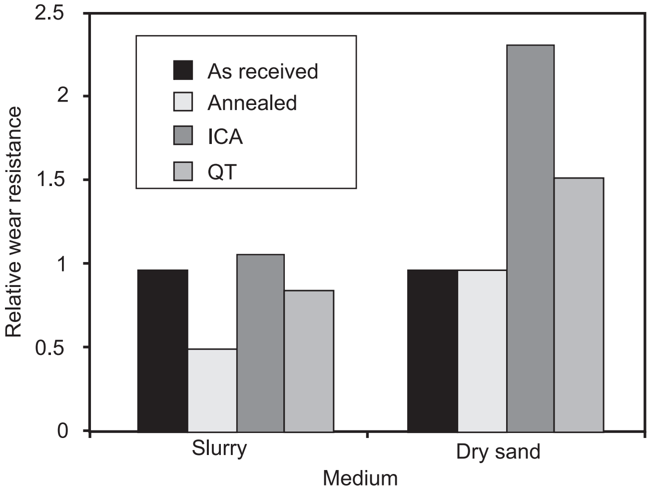
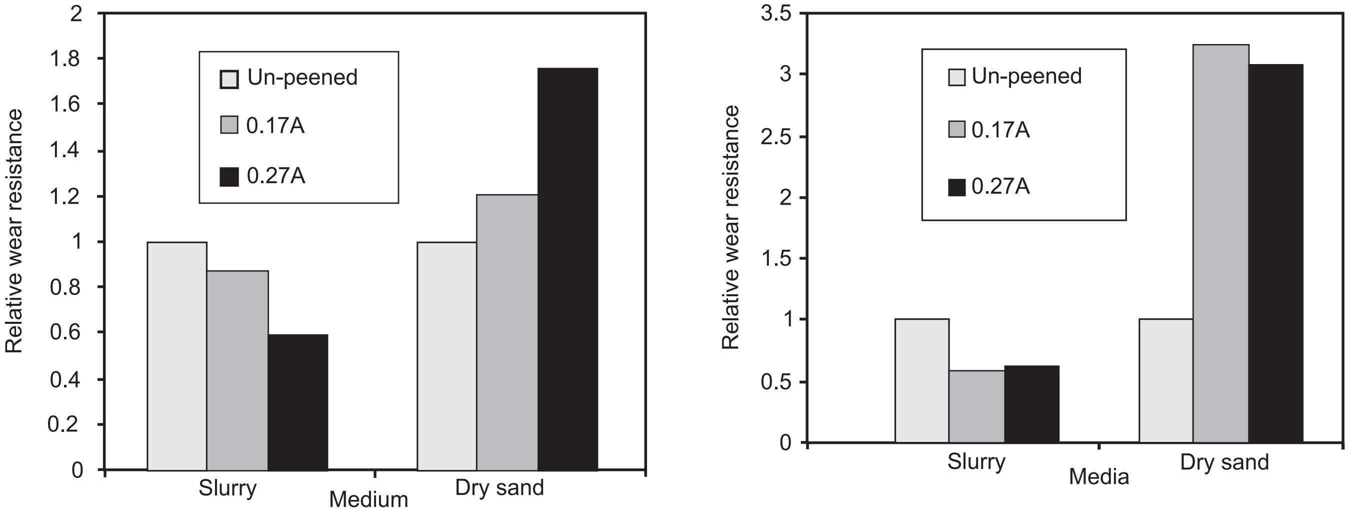


Fig 4a Effect abrasive media and heat treatment process on relative abrasive wear resistance of un-peened 50B50 steel at 200 N load in slurry and dry sand



(i) ICA (ii) QT

Fig 4b Effect abrasive media and peening intensity on relative abrasive wear resistance of 50B50 steel (ICA & QT) at 200 N load in slurry and dry sand specimen, in slurry condition the relative wear resistance decreased to 57.86 % and 62% of un-peened specimen when peened at 0.17 A and 0.27 A intensities as comparable to un-peened specimen. This strengthens the fact that effect of peening on slurry abrasion is almost of similar kind in both the heat-treated conditions. In case of dry condition the relative wear resistance increases 3.235 times when peened at 0.17 A. Further increase in peening intensity to 0.27 A leads to decrease the relative wear resistance with respect to 0.17 A peening intensity but considerably higher than un peened sample (307.8%). The relative wear resistance of QT specimens (which is hard and brittle before peening) starts decreasing due to formation of crack and increase in brittleness due to peening.

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