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Effect of Heat Treatment on Wear Rate of Different Agricultural Grade Steels and Associated Cost Economics

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ABSTRACT

An investigation was conducted to study the effect of heat treatment processes on agricultural grade steels to enhance their life and associated cost economics. Three different types of agricultural grade steels (mild steel (MS), medium carbon steel (MCS) and medium carbon low alloy steel (MCLAS)) underwent heat-treatment processes. MS was carburized (950 °C for 720 min), MCS and MCLAS were austenised at 900 and 850 °C for 120 min. These steels were oil quenched and tempered at 200, 300 and 400 °C. The steel specimens were evaluated in laboratory condition using dry sand abrasion tester before and after heat-treatment. Effect of heat-treatments on abrasive wear, hardness and associated cost economics were studied. The results exhibit that under heat untreated conditions, wear rate of MCS and MCLAS were 13.10% and 32.33% less than that of MS. Whereas, under heat treated specimens wear rate reduced by 18.83%, 36.94% and 48.13% in MS, MCS and MCLAS, respectively. The hardness of all steels after heat treatment was found to increase more than two fold. Enhancement in the life of the selected steels were found to be 64.83% higher in case of MCLAS followed by 45.15% in case of MCS over MS. Maximum increase was seen in cost of ₹ 70/kg and ₹ 45 /kg in MCLAS and MCS at 200 °C tempering temperatures, respectively.

Keywords: Steels, heat treatment, wear rate, hardness and cost economics

Agricultural machinery components are severely subjected to abrasive wear, combined effect of chemical action and loading during field operation (Hugo *et al.* 2013; Severnev, 1984). The phenomenon of abrasive wear results in failure and replacement of components which in turn exerts influence on field capacity, field efficiency and operational cost (Bobobee *et al.* 2007). Wear is a surface phenomena, and it is associated with the surface hardness of the component. Generally, wear resistance increases with hardness but after a certain limit it may lead to increase in brittleness. The brittleness of the components cause cracking on the surface and increases the wear rate on the surface of the component due to the removal of material in the form of chips or flacks. Tiny soil or crop particles behave like a tool on the component surface to remove the material. Combination of properties such as hardness and toughness is preferred to overcome the problems. Steels are widely used material for agricultural machinery manufacturing applications with different treatments mainly because of its ability to attain a wide range of properties, such as hardness, strength, toughness and wear resistance (Agrawal, 1988). Different heat-treatment processes highly influence the microstructure, mechanical properties and wear resistance of agricultural grade steels (Golanski, 2010; Singh *et al.* 2010 &14). Literature reviews about bulk treatment (Bhakat *et al.* 2007; Singh *et al.* 2010 & 14; Beata and Piotr, 2015) and surface treatment such as diffusion processes like carbonization (Jankauskas and Skirkus, 2013), nitriding, boriding, surface coatings (Khan, 2010), hard facing (Horvat *et al.* 2008; Annappa and Basavarajappa, 2013; Ulutan *et al.* 2011), hot stamping and hard facing (Yazici, 2011) and shot peening (Singh *et al.* 2011) on various soil working components like mould board plough share, rotavator blade etc. The mentioned treatments change the micro-structural constituents of the material and alters the hardness and mechanical properties. Heat-treatment processes provide extremely excellent combination of mechanical as well as tribological properties. Among all the heat-treatment processes, quenching and tempering is a commonly used popular method to improve the wear resistance and hardness of agricultural implements (Singh and Mondal, 2012).

All the surface treatment processes like hard facing and shot peening improve the surface properties of the components as the effected surface is worn out. The component starts behaving like untreated component and requires treatment again. In agricultural engineering applications, most of the work pertaining to material selection and its bulk or surface treatment is carried out to enhance the life of fast wearing components by the reduction of wear. Agricultural machinery users always expect low cost, good quality and long lasting machines. Small machinery manufacturers lack the good manufacturing facilities, which leads to the manufacturing of inferior quality machines. Majority of these manufacturers use mild steel (Rautaray and Sharma 1996; Gupta *et al.* 2004 and Saxena and Sharma, 2001) and used leaf spring (Raval and Kaushal, 1990) etc., but now researchers have started to use boron steels (Singh and Mondal, 2012; Singh *et al.* 2010 and Bhakat *et al.* 2007) and low alloy medium carbon steels (Singh *et al.* 2011 & 2014). Therefore, the present study was undertaken to select the appropriate material and treatment for agricultural machinery by using a well simulated methodology for inducing abrasive wear resistance of all steels in the same condition to enhance their life and associated cost involved to select the appropriate cost competitive material for longer service life.

MATERIALS AND METHODS

The study was conducted at ICAR-Central Institute of Agricultural Engineering, Bhopal during 2013–14. Specimens for microstructural, mechanical and wear testing were made from mild steel (MS), medium carbon steel (MCS) and Medium carbon low alloy steel (MCLAS). The chemical composition analysis was done and given in Table 1.

Table 1: Chemical composition of steels used for the study

Steel type	Chemical composition (Wt basis)				
	C	Si	Mn	P	Cr
MS	0.14	0.21	0.43	0.028	—
MCS	0.44	0.23	0.50	0.32	—
MCLAS	0.52	0.22	0.70	0.027	0.70

Selected steels underwent heat-treatment processes at Indo-German Tool Room, Indore. The details of the selected steel types and heat treatment processes are given in Table 2.

After heat treatment each specimen was polished and the hardness of the specimens was measured using Rockwell hardness tester. Abrasive wear tests were undertaken by the rubber wheel dry sand abrasion test machine as per ASTM G-65. The schematic view of the M/s DUCOM, Bangalore, Rubber wheel dry sand abrasion test machine is shown in Fig. 1a &b. In this test, a rubber wheel of 177.8 mm diameter and 12.7 mm width is rotated in a specified speed against the stationary flat specimen of size 76.2 mm × 25.4 mm × 6 mm and held firmly over the wheel surface. Crushed silica sand is used as abrasive medium during evaluation. The wheel is rotated at a fixed speed of 1.86 m/s and moved up to a distance of 2.6 km. All the tests in the study were conducted at 75 N load.

After the completion of each of the test, the specimens were weighed. Wear rate W_R of the specimen was measured from the weight loss measurement at a regular interval of 144 m of sliding distance by using formula (1).

$$W_R = (Wi - W_f) / (S) \qquad \ldots(1)$$

Where,

W_i - Initial weight of specimen before the test, g
W_f - Final weight of specimen after the wear test, g
S - Sliding distance, m
W_R - Wear rate, g/m

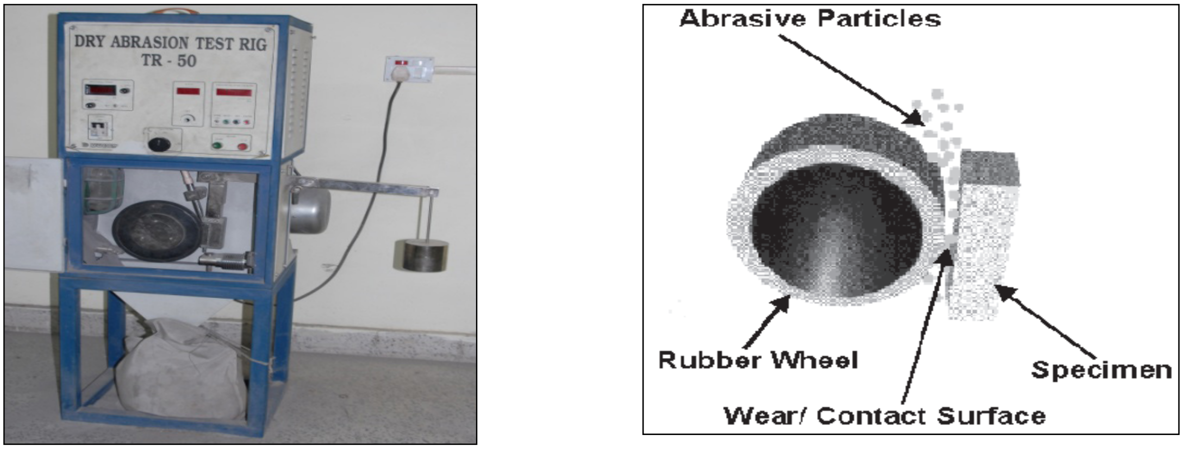
RESULTS AND DISCUSSION

Microstructure and mechanical properties of steel

Hardness of untreated and treated steels is given in Table 3. It is evident from this table that in

Table 2: Heat-treatment process of the steels used for the study

Steel type	Austenising temperature (^{0}C)	Socking time (min)	Quenching medium	Tempering temperature (^{0}C)	Tempering time (min)
MS	950	720	Oil	200, 300,400	120
MCS	900	120	Oil	200, 300,400	120
MCLAS	850	120	Oil	200,300,400	120



(a) Rubber wheel dry sand abrasion test machine

(b) Schematic of the rubber wheel and specimen during wear test

Fig. 1: Abrasive war test setup

Table 3: Hardness of steel before and after heat-treatment

Steel		Hardness (HRc)		
	Before treatment	After treatment (At various tempering temperature ^{0}C)		
		200	300	400
MS	16	37	34	29
MCS	20	42	37	31
MCLAS	21	48	43	41

untreated condition the micro-structure of all three steels containing pearlitic colonies with ferrite net-work converts to tempered martensitic structure with small amount of retained austenite during heat-treatment process. It is also noted that due to the formation of hard martensitic structure, the hardness and strength of these steel components also increase twice of the un-treated steels. In case of mild steel the harder microstructure i.e. martensite is present only up to a few microns and at the core of the specimen the microstructure is pearlitic colonies with ferrite net-work, which is softer than the surface. As the carburized surface gets worn out during abrasive wear test, the specimen starts behaving almost similar to untreated specimen.

Effect of heat-treatment on hardness of the steels

It is evident from the Table 3 that hardness of MS is the lowest among all the investigated steels. It is due to less carbon present in this steel. The percentage improvement in the hardness was found 131.25%; 112.5% and 81.25%; 110%, 85% and 55%; 128.57%, 104.76% and 95.24 % after heat-treatment. The percentage improvement in hardness of MS was found to be the highest because the initial hardness of MS was low and after carburizing the surface carbon content in MS specimen increases in the range of medium carbon or even in the range of high carbon steel after quenching and tempering surface properties is similar to medium carbon steel due to the formation of tempered martesitic structure at the surface of the MS. The hardness of MCLAS was found maximum due to the formation of hard chromium carbides during the quenching process.

Effect of chemical composition and sliding speed on abrasive wear

Effects of chemical composition on the abrasive wear rate of untreated and treated steels are shown in Fig. 2a & 2b, respectively. It is evident from this figure that abrasive wear significantly gets affected by the composition of the steel. MS shows maximum wear rate followed by MCS and MCLAS at 0.93 m/s. A similar trend was observed when specimens were tested at 1.86 m/s, 2.76 m/s and 3.72 m/s.

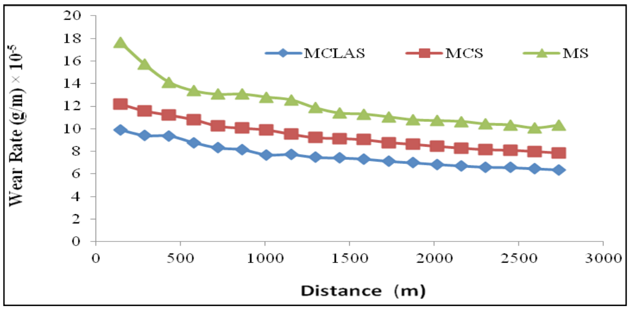


Fig. 2 (a): Untreated steels

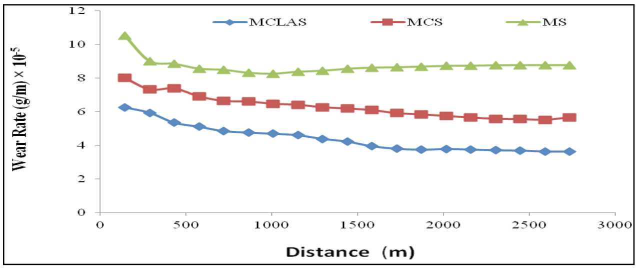


Fig. 2 (b): Treated steels

Fig. 2: Effect of sliding distance on wear rate at 0.93 m/s

It is noted that in carburized MS, the wear rate was found to have increased as soon as the carburized surface had worn-out after a sliding distance of about 1500 m as depicted from Fig. 2(b). It is apparent from these figures that the wear rate decreases with sliding distance irrespective of the steel type and treatment and reaches to the stable steady state value. Initially, the wear rate is higher due to poor surface properties of the steel specimen. During heat treatment process or any other treatment when components surface temperature is high, the carbon available at surface burns with atmospheric oxygen and forms carbon dioxide. This gives poor surface properties. Again, lowering of the wear rate with sliding distance is due to subsurface work-hardening because of the subsurface plastic deformation during abrasive wear. The wear rate could be reduced significantly through heat treatment (QT) by the generation of tempered martensitic structures that exhibit excellent combination of mechanical properties like strength and toughness to control the abrasive action by the sand particles.

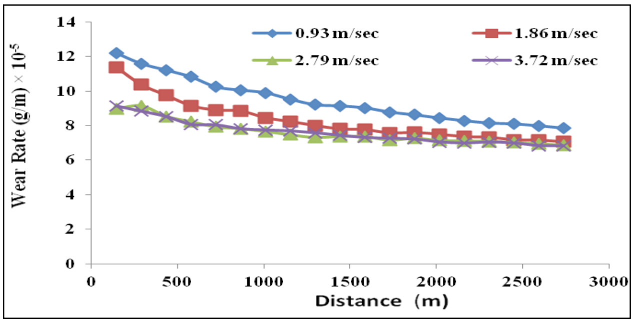


Fig 3 (a): Untreated MCS

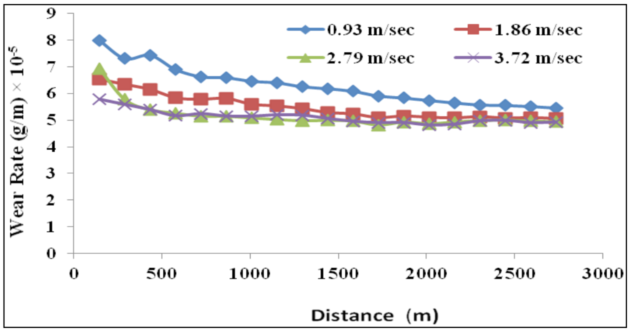


Fig 3 (b): Heat treated MCS

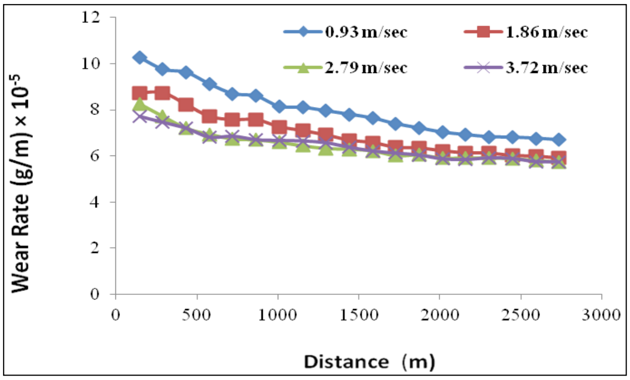


Fig 3 (c): Untreated MCLAS

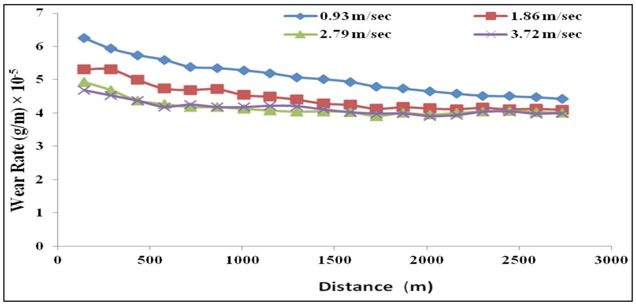


Fig 3 (d): Heat treated MCLAS

Fig. 3: Effect of Sliding speed on abrasive wear behaviour of steels at different sliding speeds

The effect of sliding speed on abrasive wear of MCS in untreated and treated condition (Fig. 3 (a-b)) and MCLAS in untreated and treated condition (Fig. 3 (c-d)) is depicted from figure -3. The wear rate was found to have reduced with an increase in sliding speed as at increased speed the sand particles get less time for penetration into the surface of the specimen which results in less scratching which in turn gives a lower wear rate. A similar trend was with specimens of MS also. The effect of sliding distance and chemical composition on wear rate has already been discussed in the precious section.

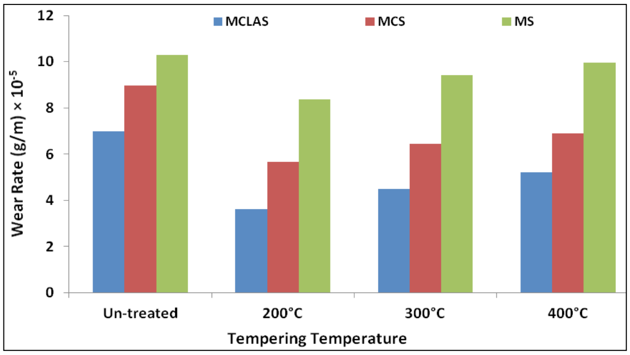


Fig. 4: Combine effect of chemical composition and tempering temperature on abrasive wear behaviour of selected steel

The combine effect of chemical composition and tempering temperature is depicted in figure-4. It clearly indicates that the abrasive wear rate decreases after heat-treatment. The wear rate of untreated MCS and MCLAS were found to be 13.10 % and 32.33% less respectively when compared to MS. Similarly the wear reduction in MCS and MCLAS were about 23.21%, and 25.07%, 28.12% and 35.53%, 36.94% and 48.13%, when tempered at 400, 300 and 200 ˚C, respectively. The reduction of wear rate of MS was observed by 3.20%, 8.60% and 18.83% when tempered at 400, 300 and 200 ˚C, respectively after carburization. It is also evident that at lower tempering temperature the wear rate is less becouse of higher hardness.

Cost Economics and enhancement in life of different type of steel

Economic evaluation in terms of cost (₹/kg) and enhancement in life (years) of different type of steel namely mild steel (MS), medium carbon steel (MCS) and medium carbon low alloy (MCLAS) after treatment at different degree of temperature was carried out and shown in Table 4. It was observed that a sizeable increase in the cost of different type of steel was found after treatment at different degree of temperature because of the improvement in the quality of steel which resulted in enhancement in life over the MS. MS was taken as the control. Highest enhancement in life and increase in cost was observed at the treatment of 200 °C due to the improvement in quality of the steels.

Enhancement in life was 64.83% higher in case of MCLAS followed by 45.15% in case of MCS over MS. Maximum increase in cost (₹ 70/kg) in case of MCLAS followed by MCS (₹ 45/kg) and MS (₹ 35/kg) was found at the treatment of 200 °C. No change in cost was observed when treated at 300 °C and

Table 4: Improvement in wear rate and increase in cost

Treatment	MS		MCS		MCLAS	
	% enhancement in life	Increase in cost (₹/kg)	% enhancement in life over MS	Increase in cost (₹/kg)	% enhancement in life over MS	Increase in cost (₹/kg)
Un-treated	—	—	13.10	15.00	32.33	40.00
400°C	3.2	35.00	33.17	45.00	49.28	70.00
300°C	8.54	35.00	37.47	45.00	56.30	70.00
200°C	18. 83	35.00	45.15	45.00	64.83	70.00

400 °C because of the reason that no improvement in quality of different type of steel had taken place. The wear rate of different grades of steels was also worked out at different level of tempering temperatures. Keeping in view the additional cost and additional return in term of wear rate reduction, it was found that the marginal rate wear of wear rate reduction was maximum in MCS followed by MCLAS and MS.

CONCLUSION

The study reveals that due to heat-treatment the hardness of the steel specimens improves more than twice and for heat untreated conditions wear rate of MCS and MCLAS was 13.10% and 32.33% less than that of MS. Whereas, under heat treated specimens wear rate reduced by 18.83%, 36.94% and 48.13%, in MS, MCS and MCLAS, respectively. Hardness of all steels after heat treatment was found to have increased more than two fold. Enhancement in the life of the selected steels was found to be 64.83% higher in case of MCLAS followed by 45.15% in case of MCS over MS. Maximum increase in cost was seen as ₹ 70/kg, ₹ 45 /kg and ₹ 35/kg in MCLAS, MCS and MS at 200 °C tempering temperatures, respectively.

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