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SELECTION OF MATERIAL AND HEAT TREATMENT CYCLE FOR WEAR REDUCTION IN OIL PALM (*Elaeis Guineensis*) HARVESTING KNIVES

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Abstract: Harvesting of oil palm is a tedious and labor intensive work. Non-availability of proper tool increases the severity of the problem. Knives used for harvesting the oil palm are either imported or made by local artisans using locally available scrap material. In the present study, oil palm harvesting knives imported from Malaysia and locally made by manufactures in Kerala, India were tested for chemical composition and hardness. On the basis of the results, medium carbon steel was selected for fabrication of oil palm harvesting knives. To obtain the various combinations of microstructure, mechanical properties and wear resistance; these knives were subjected to quenching and tempering treatment with varying tempering temperature (from 250 to 550°C at an interval of 50°C). Abrasive wear resistance of this steel before and after heat-treatment was studied in laboratory using dry sand abrasion test rig as per ASTM G 65 standard at different rotational speed of rubber wheel ranging from 50 to 200 min^{-1} at an interval of 50 min^{-1}. The study revealed that both the factors i.e. tempering temperature and rotational speed of rubber wheel exerted significant influence on abrasive wear resistance. At 250°C tempering temperature, the hardness and abrasive wear resistance is observed to be maximum under the laboratory evaluation. Similar wear resistance behavior was also observed under field condition when the knives were used to cut frond and bunch of oil palm by human laborers.

Key words*: wear rate, steel, heat-treatment, mechanical properties, oil palm harvesting*

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INTRODUCTION

India is the third largest importer of vegetable oils, after China and European Union. The major demand of palm oil arises from the food and cooking oil industries. It is a tree having single stem and pinnate (feather like) leaves. The harvesting of fruits continues till the plant attains 15-20 m height. Harvesting of fruits from the trees taller than 20 m is very difficult. As this is the stage of obtaining maximum productivity from the oil palm, therefore, there is a burning need for development of harvesting devices for these long trees. At present, farmers mostly rely on hand held harvesting tool which is basically a harvesting knife fitted at the end of a long metallic pole or bamboo as depicted in Fig. 1.

Figure 1. Oil palm harvesting knife and harvesting operation

In crop cutting and soil engaging agricultural operations, components are severely subjected to combined effect of chemical action, impact and fatigue loading, operating conditions [1] as well as abrasive wear [2]. These factors exert some influence on the field efficiency and operational cost of the machine [3]. An excellent combination of mechanical as well as tribological properties is desired to overcome the problems arising out of such operational condition. Steel is a widely used material for such applications mainly because of its attaining a wide range of properties, such as hardness, strength, toughness, wear resistance etc., which is not found in any other family of materials [4]. Different alloying elements [5], heat-treatment processes [6,7] and surface modification technologies such as diffusion processes like carburising, nitriding, boriding, surface coatings [8], hard facing [9-11], hot stamping and hard-facing [12] and shot peening [13] processes have been attempted to alter the properties of steels. All above-mentioned treatments change the micro-structural constituents of the material, which alter the hardness and mechanical properties of the steel to induce wear resistance in agricultural machinery. Heat-treatment processes provide extremely excellent combination of mechanical as well as tribological properties. Among them, quenching and tempering is a commonly used popular method to improve the wear resistance and hardness of agricultural implements [14, 15]. Above review indicates that in agricultural engineering applications most of the work pertaining to material selection and its bulk and surface treatment is carried out on soil engaging components like plough share, rotary plough etc and a few attempted has been made for crop cutting components. All the surface treatment process like hard facing, shot peening improves the surface properties of the components as the effected surface is worn out, the component starts behaving like untreated components and requires treatment again. Keeping this fact in mind, the present study was carried out to select appropriate material for fabrication of oil palm harvesting knife and subjecting them to various heat treatment cycles for inducing abrasive wear resistance for higher service life.

MATERIAL AND METHODS

The study was conducted at *ICAE*- Central Institute of Agricultural Engineering, Bhopal and *ICAR*- Indian Institute of Oil Palm Research (*IIOPR*), Pedavegi, Andhra Pradesh during 2013 – 14. One local and two imported oil palm harvesting blades that were being used in India for oil palm harvesting were provided by ICAR- Indian Institute of Oil Palm Research (*IIOPR*), Pedavegi, Andhra Pradesh. Chemical composition and hardness test of the material of these blades were carried out by using Spectroscope and Rockwell hardness tester. Based on these test results, medium carbon steel having comparable chemical composition was selected for manufacturing oil palm harvesting knives. The manufactured knives were subjected to heat-treatment (oil quenching after austenised at 860°C followed by tempering) at Indo-German Tool Room, Indore, Madhya Pradesh as shown in Fig. 2. Tempering was done at different temperatures ranging from 250°C to 550°C for obtaining different combination of mechanical and tribological properties. Specimens made from above heat treated steel sheet were used for microstructural, mechanical and wear testing. After polishing, the hardness of the specimens was measured using Rockwell hardness tester.

Figure2. Heat treatment of oil palm harvesting knives

Abrasive wear was conducted using *DUCOM* dry sand abrasion test rig to measure the wear rate following *ASTM* standard *G-65*. Before testing, the specimens were cleaned, polished according to the standard metallographic techniques, weighed by the electronic balance and then fitted in the specimen holder of the test rig. The specimens were tested at a load of 75 N with four rotational speeds of rubber wheel i.e. 50 min^{-1} (0.93 $m \cdot sec^{-1}$), 100 min^{-1} (1.86 $m \cdot sec^{-1}$), 150 min^{-1} (2.79 $m \cdot sec^{-1}$) and 200 min^{-1} (3.72 $m \cdot sec^{-1}$). The machine stopped after completion of pre-set 200 revolutions. The specimens were then taken out, cleaned and weighed to measure the weight loss due to abrasion. This process was repeated periodically after an interval of 200 revolutions (corresponding to sliding distance of 144 m) till the required sliding distance of 2.6 km was covered. The experiment was replicated thrice and the average values of these three tests were considered.

During tests, wear rate (*WR*) of the specimens were measured from the weight loss measurement at a regular interval of 144 m of sliding distance by using Eq. (1).

$$WR = (W_i - W_f) / (S) \qquad (1)$$

where:

W_i [g] - initial weight of specimen before the test,

W_f [g] - final weight of specimen after the wear test,

S [m] - sliding distance.

Factorial Randomized Complete Block Design (*RCBD*) with two factors was adopted for conducting the experiment. A total of eight heat treatment methods, i.e., seven different tempering temperatures and one control (un-tempered) were selected as main factor in the experiment. Four different rotational speeds were selected as sub-factor and all the treatments were replicated thrice in the experiment. The interaction effects between these factors were also estimated to find out the significance of their influence.

The oil palm harvesting knives were evaluated in oil palm orchard for cutting the bunch of oil palm fruits after removing the frond (leaf petiole) engulfing each bunch. The usual plant to plant and row to row spacing for oil palm is 9 m× 9 m with an average plant population of 144 per hectare. Each heat treated harvesting knife was randomly allocated to human labourers for cutting 100 fronds and bunches from oil palms with three replications. After completion of harvesting operation, the wear of material was measured for each knife by electronic balance and expressed in terms of gram per hectare. The experimental data were analysed using *SAS* 9.3 statistical software of *SAS* Institute Inc., USA to find out the significance of the influence of different heat treatment methods on harvesting knives.

RESULTS AND DISCUSSION

The selected oil palm harvesting knives were tested for their chemical composition and hardness. As evident from their chemical composition, medium carbon steels were preferred for making oil palm harvesting knives as given in Tab. 1. The carbon percentage in harvesting knives varied from 0.26 % to 0.46 % along with other alloying elements like silicon, manganese, phosphorus and sulphur etc. which indicated that plain carbon steel was used in these harvesting knives.

The analysis also revealed that the hardness values of the imported knives were in the range of 27-32 *HRc*. Whereas; it was only 16 *HRc* in case of local knife, which was almost 40-50% less as compared to that of imported knives. Less hardness value of these knives is the indication of improper heat-treatment given to them [16]. Based on the chemical analysis, medium carbon steel containing 0.54% carbon, 0.23% silicon, 0.69% manganese, 0.01% phosphorus and 0.008% sulphur was selected for making knives for oil palm harvesting.

Table 1. Chemical composition and hardness of commercial blades

Type of blade	*Chemical Composition [% wt. basis]*					*Hardness [HRc]*
	C	*Si*	*Mn*	*P*	*S*	
Imported-1	*0.46*	*1.47*	*0.57*	*0.023*	*0.037*	*32*
Imported-2	*0.26*	*0.54*	*0.60*	*0.18*	*0.017*	*27*
Local	*0.30*	*0.83*	*0.53*	*0.03*	*0.042*	*16*

After heat-treatment, the hardness of the selected material was tremendously increased. Due to formation of martensitic structure, the hardness of steel increases up to 48 *HRc* after austenizng and quenching in oil as given in Tab. 2, which was reduced to the range of 43 to 25 *HRc* after tempering at different temperatures.

Table 2. Tempering temperature and hardness of the heat-treated knives

Treatment	*Untreated*	*Quenched and untempered*	*Tempering temperature [°C]*						
			550	*500*	*450*	*400*	*350*	*300*	*250*
Hardness [HRc]	*18*	*48*	*25*	*27*	*31*	*34*	*37*	*39*	*43*
Increase in hardness [%]	*-*	*167*	*39*	*50*	*72*	*89*	*106*	*117*	*139*

The effect of sliding distance on abrasive wear rate of control specimen is given in Fig. 3. It was observed that the wear rate reduced initially at a faster rate with increase in the sliding distance during abrasion test irrespective of speed **(**0.93, 1.86, 2.79 and 3.72 $m \cdot s^{-1}$) and finally attained a steady state value. Lowering of the wear rate with sliding distance was due to subsurface work-hardening resulting from subsurface plastic deformation during abrasive wear. Continuous plastic deformation caused work-hardening of the material and wear rate was reduced monotonically with sliding distance as per expectation. But other phenomena like surface and subsurface cracking as well as frictional heating at the subsurface resulted into annihilation of this effect after some time. Same trend of wear rate was also observed for heat treated specimens. The effect of tempering temperature on abrasive wear rate is depicted in Fig.4. It was observed that wear rate reduced with decrease in tempering temperature due to higher hardness value of the material at lower tempering temperatures. Once the tempering temperature reduced below 350℃, the wear rate remained unchanged due to less variation in hardness and other mechanical properties.

The analysis of variance of the factorial experiment is presented in Tab. 3. It was observed that both the tempering temperature and the rotational speed has significant influence on wear rate independent to each other as their interacting influence was found to be non-significant on wear rate.

Among different tempering temperatures applied in this experiment, minimum wear rate was observed when the material was treated at a tempering temperature of 250°C. Wear rate was observed to be increasing with increase in tempering temperature and the control specimen exhibited minimum resistance to abrasive wear (Tab. 4). On the other hand, the resistance to abrasive wear was increasing with increase in rotational speed of the wheel due to less contact time between the wheel and the specimen. Minimum abrasive wear was experienced at a rotational speed of 150 and 200 min^{-1}.

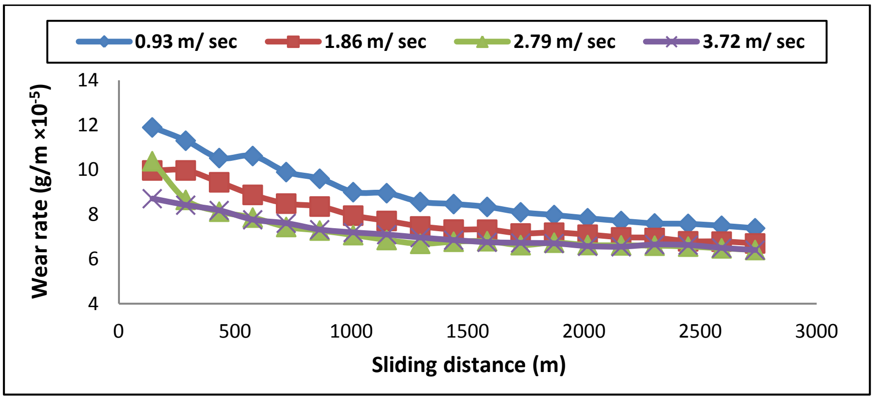

Figure3. Effect of sliding distance on abrasive wear rate of un-treated steel

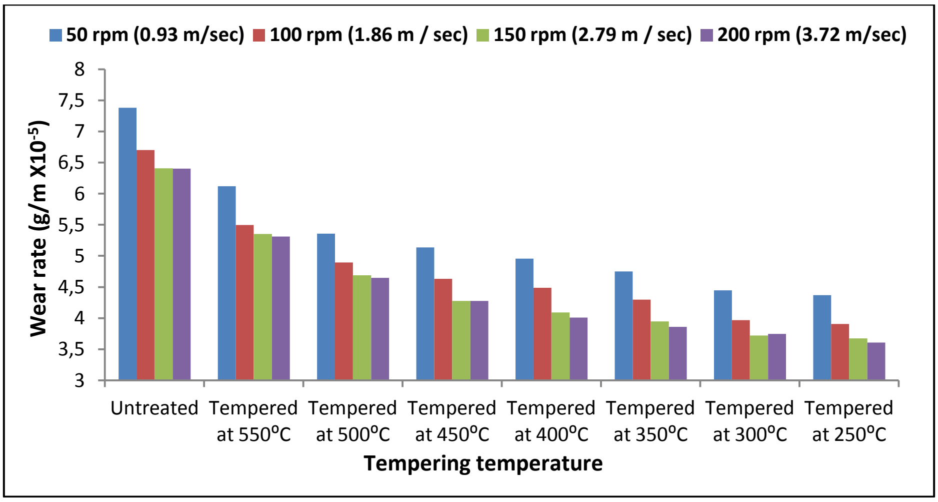

Figure 4. Effect of tempering temperature on abrasive wear rate

The maximum resistance to abrasive wear was obtained when the specimens were subjected to heat treatment applying tempering temperature of 250°C with 200 min^{-1} rotational speed of the wheel (Tab. 5). However, comparable wear resisting behaviour was also observed in the specimens treated at a tempering temperature of 250°C to 350°C with a rotational speed ranging from 150 to 200 min^{-1}. Therefore, the selection of appropriate combination of these two factors is based on their individual influence on wear resistance as the interaction effect was found to be non-significant.

Table 3. Analysis of variance of tempering and speed of operation on wear rate

Source	*Degree of freedom*	*Sum of square*	*Mean sum of square*	*F ratio*
Replication	*2*	*5.4131*	*2.7065*	*17.26****
Tempering temperature [°C]	*7*	*76.5549*	*10.9364*	*69.74****
Speed (min^{-1})	*3*	*10.6770*	*3.5590*	*22.69****
Tempering temperature × min^{-1}	*21*	*0.2689*	*0.0128*	*0.08 ns*
Error	*62*	*9.7234*	*0.1568*	---
Corrected total	*95*	*102.6374*	---	---

**** - Significant at 1% level, ^{ns} – not significant*

Table 4. Wear rate at various tempering temperature and rotational speed

Particular of factor	*Average wear rate [$g \cdot m^{-1} \times 10^{-5}$]*	*Least Significant Difference (LSD) at 5% level*	*Tukey's grouping for comparison*
Tempering temperature			
250°C	*3.8898*	*0.3232*	*G*
300°C	*3.9698*		*FG*
350°C	*4.2135*		*EF*
400°C	*4.3857*		*DE*
450°C	*4.5793*		*CD*
500°C	*4.8973*		*C*
550°C	*5.5692*		*B*
Un-treated	*6.7236*		*A*
Speed [min^{-1}]			
50	*5.3149*	*0.2285*	*A*
100	*4.8009*		*B*
150	*4.5163*		*C*
200	*4.4820*		*C*

Table 5. Two factor interaction effect on wear rate

Interaction of tempering temperature and speed [min^{-1}]	*Average wear rate [$g \cdot m^{-1} \times 10^{-5}$]*	*Least Significant Difference (LSD) at 5% level*	*Tukey's grouping for comparison*
250 × 50	*4.371*	*0.647*	*EFGHI*
250 × 100	*3.906*		*GHI*
250 ×150	*3.676*		*HI*
250 × 200	*3.606*		*I*
300 × 50	*4.446*		*EFGHI*
300 × 100	*3.969*		*GHI*
300 × 150	*3.718*		*HI*
300 × 200	*3.746*		*HI*
350 × 50	*4.752*		*EFGHI*
350 × 100	*4.323*		*EFGHI*

350 × 150	*3.920*		*GHI*
350 × 200	*3.858*		*GHI*
400 × 50	*4.955*		*DEFGH*
400 × 100	*4.488*		*EFGHI*
400 × 150	*4.092*		*FGHI*
400 × 200	*4.008*		*GHI*
450 × 50	*5.134*		*CDEFG*
450 × 100	*4.631*		*EFGHI*
450 × 150	*4.278*		*EFGHI*
450 × 200	*4.274*		*EFGHI*
500 × 50	*5.359*		*CDEF*
500 × 100	*4.894*		*DEFGH*
500 × 150	*4.687*		*EFGHI*
500 × 200	*4.648*		*EFGHI*
550 × 50	*6.120*		*ABCD*
550 × 100	*5.495*		*BCDE*
550 × 150	*5.350*		*CDEF*
550 × 200	*5.312*		*CDEF*
Un-treated × 50	*7.381*		*A*
Un-treated × 100	*6.702*		*AB*
Un-treated × 150	*6.408*		*ABC*
Un-treated × 200	*6.403*		*ABC*

Field evaluation. In field experiment, it was observed that oil palm harvesting knives quinched and tempered at a temperature of 250°C after austenizing gave the minimum wear rate of 2.288 g·ha^{-1}, which is significantly different from that of control treatment (Tab. 6). However, the heat treatment process of quinching and tempering at a temperature of 300°C after austenizing also exibited similar wear resistence behaviour with a comparable wear rate of 2.402 g·ha^{-1}. Further increase in tempering temperature augmented the wear rate in oil palm harvesting knives. During field evaluation at oil palm planation, Pedavegi, it was found that harvesting of oil palm by using improved knife takes 35 to 40 minuted less time than that of traditional knife , which implies that a saving of 16 % time was achieved (Tab. 6) for harvesting the same number of plants.

Table 6. Wear rate of different heat treated oil palm harvesting knife in field

Treatment	*Mean wear rate [g·ha^{-1}]*	*SEM*	*Duncan's Rank*	*Average time saving in comparision to control [%]*
250°C	*2.288*	*0.003*	*B*	*16.00*
300°C	*2.402*	*0.001*	*B*	*15.00*
350°C	*2.955*	*0.004*	*BA*	*11.50*
400°C	*3.470*	*0.002*	*BA*	*11.00*
450°C	*5.015*	*0.000*	*BA*	*10.50*
500°C	*4.919*	*0.005*	*BA*	*09.50*
550°C	*5.034*	*0.002*	*BA*	*09.00*
(control)	*5.691*	*0.006*	*A*	*0.00*
LSD at 5%	*2.8706*			

CONCLUSIONS

The wear rate decreases with sliding distance and obtained a steady state condition after 1800 m, irrespective of tempering temperature and sliding speed. For achieving maximum resistance to abrasive wear in the material and enhancement in service life of oil palm harvesting knife, heat treatment with tempering temperature of 250℃ for 90 minutes gives best results both in laboratory as well as under field conditions. This study further reveals that use of improved knife increases work efficiency by 16 percent.

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IZBOR MATERIJALA I CIKLUS KALJENJA RADI SMANJENJA HABANJA NOŽEVA ZA BERBU

Dushyant Singh[1], K.P. Saha[1], Ravindra Naik[1], V. Bhushanbabu[1], M.V. Prasad[2], T Vidhan Singh[3]

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Sažetak: Berba palmi je naporan i intenzivan postupak. Problem je izraženiji zbog nedostatka odgovarajućih alata. Noževi koji se koriste se uvoze ili ih izrađuju lokalne zanatlije od otpadnog gvožđa. Ovde su ispitivani noževi uvezeni iz Malezije i noževi lokalne proizvodnje, a određivan im je hemijski sastav i tvrdoća. Na osnovu rezultata izabran je srednje ugljenični čelik za izradu noževa. Za dobijanje različitih kombinacija mikrostrukture, mehaničkih osobina i otpora habanju ovi noževi su grejani i naglo hlađeni na različitim temperaturama (od 250 do 550°C u intervalu od 50°C). Otpor ovog čelika na abrazivno habanje pre i posle kaljenja je ispitivano u laboratoriji upotrebom abrazivnog testa sa suvim peskom prema standardu *ASTM G 65*, sa različitim brzinama rotacije gumenog točka, od 50 do 200 min^{-1} u intervalu od 50 min^{-1}. Ispitivanjem je utvrđeno da su oba faktora, temperature kaljenja i brzina rotacije gumenog točka, imala značajan uticaj na otpor abrazivnom habanju. Na temperature od 250°C dobijeni su maksimalna tvrdoća i otpor habanju u laboratorijskim uslovima. Sličan otpor habanju uočen je i u poljskim uslovima, kada su noževi korišćeni za ručno sečenje lišća i grana.

Ključne reči*: stepen habanja, čelik, kaljenje, mehaničke osobine, berba*

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