

## DEVELOPMENT AND TESTING OF SWEEP SHOVELS IN FIELD

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Sweep shovels fabricated using three different materials; two levels of each of heat treatment and edge thickness were field tested to establish differential responses of various parameters. Depth control wheels especially designed for the local sweep cultivator were also tested for their performance. Mild steel and medium carbon steel wore 89.3 and 64.3 percent faster than the high carbon steel. Local heat treatment, though different from international methods, improved tool's wearing ability by 37.4 percent. As the edge thickness of tool increased from 6.35 - 7.94 mm, wear decreased by 2.7 percent. Depth wheels desirably controlled operational depth of the sweep cultivator.

**Keywords:** Sweep shovels, materials, cultivator, wear, depth, wheel

### INTRODUCTION

Tine cultivator is the most popular tillage implement in Pakistan. The implement got 5.7 cm wide tines on shanks 22.9 cm apart. With this arrangement of tools, the implement skips untilled soil between tools and thus necessitates several plowings for ideal seedbed. Alternatively, the same tines replaced with 25.4cm wide sweep shovels (implement called sweep cultivator) provide an overlap of tools and reduce the passes to nearly one-half compared with tine cultivator (Sial *et al.* 1981). In view of this, sweep cultivator was developed, and its comparative performance studied along with other local implements. Sweep cultivator was considered an economical and better choice compared with tine cultivator under the farming conditions of Pakistan. (Sial and Khan, 2004). However, the sweep cultivator often encountered problems of tool breakage and a poor control over the depth of penetration. Wing and tip breakage apart from surface cracks were also common (Aleem, 1997). Previous efforts by local scientists suggest that the sweep cultivator is an ideal replacement of conventional tine cultivator as the former reduces number of passes for a desirable seedbed, in addition to conserving soil moisture and offering better nutrients management in the top soil layer (Sial *et al.* 1981; Sheikh *et al.* 1979, and). All this demands adoption of the implement by the country farmers. However, prohibitive costs of imported shovels and field problems of locally manufactured tools suggest further investigations into development and testing of shovels using local materials and workmanship. Accordingly, the present project was planned with the following specific objectives.

- (a) Using and testing local materials along with their heat treatments for fabrication of sweep shovels.
- (b) Investigating effects of macro-shape variations on strength and durability of the shovels.

- (c) Developing and testing depth wheels for controlling penetration of the indigenous cultivator with sweep shovels.

### MATERIALS AND METHODS

Present study was conducted for investigating technical feasibility of local materials, heat treatment methods and macro shape variables for fabrication of sweep shovels. Development and testing of depth control wheel(s) was also included among the experimental objectives.

#### Selection of Factors and their Levels

To select local materials for investigations, a market survey was conducted and three materials identified that were being already used for manufacturing tillage tools and other similar jobs. Carbon contents of the materials were determined at Shipyard Laboratory Karachi as 0.20, 0.32 and 0.6 percent and the materials were designated as Mild Steel, Medium Carbon Steel and High Carbon Steel respectively in the light of guidelines provided by Kalpakjian and Schmid, 2004.

For selection of heat treatment technique(s), market survey revealed that tillage tools were heat treated using an indigenous method, which included heating the machine part to red hot point in a coal fired furnace, immersing the part in a powder of Sodium Cyanide followed by quenching in water at room temperature. The method was selected for its comparison with no heat treatment. Therefore, the heat treatment factor was included at two levels of "With Heat Treatment" and "Without Heat Treatment". Furnace temperature was also measured in order to explain the response of the treatment method.

As the edge thickness of a tillage tool is a decisive factor in the wear life of tool, in addition to its serious implications on energy requirements (O' Callaghan,

2006 and Gupta and Pandya, 1967), it was decided that the edge thickness of tool should be included at two levels, that is, 6.35 mm and 7.94 mm.

In order to broaden the scope of experiment and applicability of results, above selected factors were studied at three different sites varying in initial soil conditions. Soil samples from the selected sites were collected and analyzed for determining their textural class using Hydrometer Method. The soil textures thus obtained were Loam, Clay and Clay Loam.

To further define soil conditions at the sites, bulk density and moisture contents of the soils were also determined prior to initiation of any tillage trial. The moisture contents were calculated according to American Society of Agricultural Engineers Standards S-358. Dry densities were determined using oven drying method. All the factors and their levels included in the experiment for field investigations of wear rates are as given in Table 1.

**Table 1. Factors and their levels for investigating tool wear**

Factor	Levels' Description
Soil (S)	Loam
	Clay
	Clay loam
Material (M)	Mild Steel
	Medium Carbon Steel
	High Carbon Steel
Heat Treatment (H)	With Heat Treatment
	Without Heat Treatment
Edge Thickness (t)	6.35 mm
	7.94 mm

Three replications and a split plot factorial design with soils in main plot and other factors in subplots were considered statistically appropriate to conduct the experiment and retrieve useful information from the observations. Sweep shovels were locally fabricated using materials and heat treatments discussed above. It was decided that a cultivator with nine sweep shovels shall represent one treatment at a time. It was therefore, necessary that nine shovels for each of the above treatments should be fabricated for field trials. As a result, a total number of 12 sets of nine shovels each, that is, 108 sweep shovels were fabricated

### Field Procedures

To start tillage trials at a site, all the equipment including MF-260 Tractor, nine tine cultivator equipped with depth wheels, 12 sets of shovels, each set with nine sweeps, sampling cores, plastic bags for soil density and moisture sampling, electronic scale with a least count of 0.01gram, wrenches for changing

sweeps etc. were brought to the field. Before starting tillage operation, soil samples were collected up to 10 cm depth with increment of 5 cm for determination of soil bulk density and moisture contents.

All sweep shovels in a treatment were weighed and installed on the cultivator, which was hitched behind the tractor. Each sweep was installed at its designated position on the cultivator. Six passes of the cultivator (representing one treatment) were made on half an acre field in the designated plot for the treatment in the plan. The depth of operation was set at 10 cm (4 inches) and it was maintained throughout the trials in the experiment. Similarly, speed of operation for the trials was 7 km per hour. After finishing trial of one treatment in its designated plot, all of the sweeps were taken off and weighed for assessment of mass losses. After this, next treatment (set of sweep shovels) was installed on the cultivator operated in its designated plot till all the treatments were completed. On the completion of work at one site, operational depths of tillage were also manually measured in order to watch performance of depth wheel. On completing work at one site, same procedure was repeated at the next two sites till the completion of one replicate. Similarly the next two replicates were completed. All this resulted in a set of data on weights of sweep shovels for determination of mass losses at various stages of trials.

### Wear Loss Assessment Using Size Reduction

Apart from mass losses of sweep shovels, the wear rates were also examined in terms of modifications in the edge thickness of tools and wear in tip area. Reduction in edge thickness was measured at three places, using an electronic Vernier Caliper with a least count of 0.01 mm, after the completion of tillage trials.

Tip area of a tillage tool has always been considered critical from the wear standpoint. Present experiment, therefore, planned to measure reduction of tip area during the field trials. Original areas of all the sweep shovels were considered constant as 29860 mm<sup>2</sup>. However, the final areas of each of 108 sweep shovels were determined as discussed next. On the completion of trials, each of the sweep shovels was placed on a paper sheet and a line drawn along its outer periphery. This provided a parabolic shaped curve. A horizontal line was drawn along the major axis of this parabolic curve, and 'X','Y' co-ordinates of several points on the curve were manually obtained. These co-ordinates were fed into AutoCAD-2005 version for calculation of area under the curve, which when subtracted from the original area, provided area worn out during filed trials. Worn out areas were calculated for all the 108 sweep shovels used during the trials.

## Development of Depth Control Wheel for Sweep Cultivator

Due to difficulties encountered in controlling operational depth of sweep cultivator with tractor's hydraulic control, development of depth control mechanism for the cultivator was considered. A simple and rugged mechanism was conceived (Shafi, 2007). The depth control wheels are attached on both sides of the front toolbar and tested for field performance by measuring penetration depths during operations.

## RESULTS AND DISCUSSION

### Effects of Various Factors on Wear of Shovels

Mass losses of sweep shovels were measured to examine the effects of three materials, two levels of heat treatment at three sites varying in soil conditions. The data were statistically analyzed (Table 2). Although soils were placed in the main plot and tested with lesser precision, yet differences in textures of the three soils have significantly contributed to the tool wear. Similar effects of varying soil conditions have been observed by others (Gill and Vanden Berg 1967). Average wear losses were 13.61, 33.11 and 21.69 grams per shovel in loam, clay and clay loam soils respectively (Table 3). In fact, the loam soil had been tilled as well as planked prior to trials and the field was extremely loose offering little resistance to the tool. The clay loam and clay sites resulted in 59.4 and 143.3 percent more wear compared with the loam soil. Higher wearing rates of tools in the two soils may be associated with clay contents, and other soil properties like dry density and moisture might have also affected the wear losses. Dry densities are also higher both for clay and clay loam soils (Shafi, 2007). Live vegetation has been observed as a source of resistance by other researches (Baver et al 1972). The differential behavior of soils / sites toward wear is associated largely with clay contents, soil dry density, moisture content, live vegetation and history of tillage at the site. The main effect of material tested statistically significant (Table 2). Average losses were 28.55, 24.78 and 15.08 grams for a shovel of mild steel, medium carbon steel and high carbon steel respectively (Table 3). Employment of DMR test further revealed that all the three materials were statistically different from one another suggesting. Mild steel and medium carbon steel wore 89.3 and 64.3 percent faster than the high carbon steel. Low (mild), medium and high carbon steels are available at the rates of rupees 60, 60 and 100 per kilogram respectively. The cost differential of the high carbon from other two types is much smaller compared with those of wearing rates. This suggests

adoption of high carbon steel for fabrication of shovels unless heat treatments for improving wear resistance are available.

**Table 2. ANOVA for wear losses of sweep shovels**

Source	DF	MS	P- Value
Rep	2	58.55	0.185
Soil (S)	2	3454.93	0.000
Error-1	4	22.06	0.000
Material (M)	2	1739.03	0.000
Heat Treatment (H)	1	1390.72	0.000
Thickness(t)	1	9.98	0.002
M*H	2	27.64	0.000
M*t	2	96.27	0.000
H*t	1	10.06	0.002
S*M	4	105.74	0.000
S*H	2	79.54	0.000
S*t	2	20.18	0.000
Error-2	66	0.96	-
Total	107	-	-

As indicated earlier, carbon percentages for mild steel, medium carbon and high carbon steels were 0.20, 0.32 and 0.62 percent. Carbon percentages are suggesting that wearing rate of a material decreases with increasing values of carbon. Apart from carbon contents of the trial materials, their tensile strengths and Brinell hardness (Bh) were also tested in the laboratories. Both the hardness as well as tensile strength values of different materials again explained the wear differentials observed.

The main effect of heat treatment tested statistically significant (Table 2). Average mass losses of the untreated shovels were 37.4 percent higher than the treated ones indicating a significant advantage of undertaking the treatment (Table 3). Conventional procedure of the heat treatment of tillage tools adopted by the local vendors is too simple and void of any scientific principles. The procedure includes heating the tool in a coal fired furnace followed by immersing it in powder of Potassium Cyanide (locally called '*Anda Pitasha*'), and later quenching in water at atmospheric temperature (25-45°C). This procedure is popular in the local market whereas, the same does not exist in the literature as such. An effort was also made to measure temperature of the furnace using thermocouples, and the temperature tuned out to be 1382-1450 °C. As discussed earlier in this temperature range, iron converts into *gamma* iron, which can absorb sodium cyanide that hardens on quenching. Local heat treatment method, though not standard one, yet it

produces reasonably good results and also leave a space for further improvement.

The main effect of edge thickness of shovels tested statistically significant (Table 2). The average mass loss per shovel was 22.50 and 23.11 grams for thicknesses of 6.35 and 7.94 mm respectively (Table 3). These losses are for six passes of the cultivator in an area of  $\frac{1}{2}$  an acre. The difference in wear loss for the two levels is small but consistent. In fact, the tool with larger thickness encounters more resistance to penetration, and therefore wears slightly faster, which is 2.7 percent.

A larger tool thickness would apparently last longer with a cost penalty due to additional energy requirement. O' Callaghan, (2006) reports an average increase of 37% and 56% in wear life as share thickness increased from 4 to 6 mm and 4 to 8mm respectively. He further measured an increase in draft force of 5% as share thickness increased from 4 to 8mm. In present study, use of larger edge thickness appears beneficial in terms of wear life as the increment in wear loss is 2.7 percent as against 25 percent larger thickness i.e. 6.35 to 7.94 mm.

One of the significant interactions is discussed. Material-heat treatment interaction tested significant (Figure 4) suggesting the medium carbon steel poorly responds to local heat treatment technique and demands some alternative one. Furthermore, it is obvious that the treated high carbon steel results in the least possible wear and ranks better than other combinations.

#### **Differential impact of front and rear toolbars on tool wear**

Wear slightly increased for the shovels on the rear toolbar (Shafi, 2007), for the reason that weeds and other organic matter accumulates on the shovels of front bar resulting in a little flow of soil over the tools, whereas the soil keeps flowing backward on the tools of the rear bar. Perhaps, the moving soil over the tools of rear bar results in additional wear compared with their counterparts on the front bar where soil is nearly stagnant.

#### **Effects of shovels positions on wear losses**

The cultivator used for trials had nine shovels on two toolbars. Wear differentials of shovels at various positions were compared. Wear was highest for the shovel at extreme right position since a tractor turning to the left sheds all the weeds riding on the shovel and frees it for faster movement of soil backward. A free movement of soil on the extreme right shovel increases its mass loss compared with other positions.

#### **Total wear losses during trials**

Overall tool wear losses during the present trials are shown in Table 4. Each tool was used over 10.93 hectares of field soils. The wear loss of a tool resulting from these trials varies from 136.04 to 257.38 grams. This loss of mass amounts to 8.92 to 16.89 percent of the original mass. Considering a limit of 65 percent loss of tool mass for discarding a tool, the wear lives in the present study varied from 103 – 197 acres. Wear lives of the sweep shovels are, of course low and reflect on the poor quality of materials used and / or heat treatments undertaken.

#### **Size Reductions of Sweep Shovels**

Apart from the mass losses of shovels, modifications in macroshape of the tools were measured at the end of present field trials. The percentage loss of thickness was smaller for the thick shovels compared with the thin ones. This difference varied from 3.12 to 13.12 percent. A thicker sweep has shown its worth in terms of a longer wear life. The losses of edge thicknesses are 31.87, 28.67 and 18.86 percent for mild steel, medium carbon and high carbon steel respectively. The benefit of using high carbon steel is again apparent. Similarly, the thickness differential of treated and untreated shovels clearly favored the treated ones in respect of longer life.

Tip wear being most critical phenomenon was estimated by comparing areas of shovels before and after trials. The average worn out areas for mild, medium and high carbon steels were 10.13, 4.63 and 3.42 percent respectively showing accelerated rates of wear of softer steel. Similarly, the tips of heat treated shovels wore nearly 2.5 percent slower than those of untreated ones.

#### **Testing depth control wheel under field conditions**

In view problems in controlling depth of operation of cultivator, a simple, rugged and cheap depth control mechanism was developed. Both the depth control wheels were installed on the front bar of the cultivator, which was used for the field trials. The implement was set to operate at a depth of 10 cm at 7 km/hour. Coefficients of variations among depths of operation measured during the trials were 7.8, 11.5 and 8.4 percent for loam, clay and clay loam respectively. The variation among the observed depths is within acceptable limits for field operations. This suggested a smooth operation of the depth control wheels on the cultivator developed in the present study.

## CONCLUSIONS

Sweep shovels manufactured using three materials, two levels of heat treatment, and two edge thicknesses were studied for their wear losses and consequently service life at three sites/soils varying in initial soil conditions. Depth control wheels were also tested for their effectiveness. Following conclusions were drawn from the field investigations.

- Average wear losses for a shovel were 13.61, 33.11 and 21.69 grams for loam, clay and clay loam soils respectively. In other words, clay loam and clay soils resulted in 59.4 and 143.3 percent more wear compared with the loam soil.
- Mass losses of sweep shovels were 28.55, 24.78 and 15.08 grams in a sweep shovel of mild steel, medium carbon steel and high carbon steel respectively. It means mild steel and medium carbon steel wore 89.3 and 64.3 percent faster than the high carbon steel.
- Average wear of the untreated tools was 37.4 percent higher than the treated ones indicating a significant advantage of undertaking the heat treatment.
- Larger edge thickness appears beneficial in terms of wear life in the present study, as the increment in wear loss is 2.7 percent as against 25 percent larger thickness i.e. 6.35 to 7.94 mm.
- The tips of heat treated shovels wore nearly 2.74 percent slower than those of untreated ones. Present study has identified tool tip as the most critical region, and therefore demands special tip treatment to minimize the wear.
- Tilling depths' variations were within acceptable limits for field operations justifying a smooth operation of depth control wheels.

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