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Development and performance evaluation of an circular soil bin for wear test of Rotavator blade

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Abstract
Wear analysis in the field is a time-consuming and expensive process. Consequently, there arose a necessity to devise a wear testing machine. Unfortunately, abrasive wear testing machines, as developed in advanced countries, are not readily accessible in India. This scarcity makes the investigation of wear-related issues at laboratory levels a challenging task in the country. The primary aim of this study was to create and assess a wear testing machine in the laboratory setting. The machine comprises a circular soil bin, support frame, power transmission system, working unit, and arm subassemblies. To evaluate the Equipment, rotavator blades were utilized in soils containing 99% sand. L-shaped blades, constructed from EN8 steel material, were affixed to the flange, and their speed was varied between 180 and 200 rpm. The experiment involved operating at a depth of 14 cm and a speed of 0.97 m/s in sandy soil with a moisture content of 8 to 10 percent. Wear tests were conducted under controlled indoor conditions within the circular soil bin for a continuous period of 100 hours. Gravimetric and dimensional measurements of the rotavator blades were recorded at 20-hour intervals in the circular soil bin. The results revealed a consistent increase in wear loss at each time interval at the chosen depth and speed of operation. The blades exhibited wear along their thickness, with the maximum wear observed at the tip of the blades.

Keywords: Abrasive wear, circular soil bin, moisture content, rotavator blade, sand

Introduction
Agriculture plays a pivotal role in India's economic landscape, with 54.6 percent of the population engaged in agriculture and allied activities contributing to 17 percent of the country's Gross Value Added. Recently, the rotavator has gained popularity among farmers for land preparation, offering time savings of 30-35 percent and cost reductions of 20-25 percent compared to traditional cultivator tillage methods (Ramulu, 2016) [17]. The rotavator efficiently creates an ideal seedbed in fewer passes, equivalent to one MB plough operation and two harrow operations. However, a significant challenge hindering the sustained use of rotavators is the wear of blades, influenced by moisture and unpredictable field conditions. The digging components of tillers, rotavator blades, and other agricultural machines are exposed to abrasive wear in the dynamic and non-stationary abrasive mass of soil. Agricultural operations, inherently prone to friction and wear, have been integral to human activities since ancient times (Mehulic *et al.*, 2005) [18]. Wear, defined as the progressive loss of material due to relative motion between a solid surface and contacting substances, poses a particular threat in agricultural machinery (Gurumoorthy *et al.*, 2007) [8]. Abrasive wear, characterized by the detachment of material from surfaces during relative motion, especially caused by the sliding of hard particles between surfaces, is particularly destructive (Chattopadhyay, 2001) [6]. Traditionally, determining wear in tillage tools through field wear tests has proven to be expensive and time-consuming (Tylczak *et al.*, 1999) [15]. Consequently, several laboratory soil bins have been developed and implemented in various countries (Al-Janobi and Eldin, 1997) [3] for fundamental and applied research, typically located in research centers and agricultural equipment manufacturing companies. Notably, none of these facilities have been established in India. Therefore, the objective of this study was to create and assess abrasive wear testing equipment specifically designed for rotavator blades and other soil-engaging implements and tools.

The evaluation focused on investigating the wear of L-shaped rotavator blades made from EN8 steel material.

Materials and Methods

Design of the circular soil bin

The primary goal in developing this equipment was to construct a tool specifically designed for conducting laboratory tests on the wear of rotavator blades. The key features of the equipment were tailored to facilitate controlled movement of the blade within the soil. As highlighted by Al-Janobi and Eldin (1997) [3], the configuration of soil bins can be either straight or circular, contingent on the nature of the study, spatial considerations, energy requirements, and financial constraints. After careful deliberation, the decision was made to design a circular soil bin for this particular equipment. The essential components of the equipment comprise the circular soil bin, support frame, power transmission system, working unit, and arm-subassemblies. Design criteria were meticulously established, with a focus on ensuring user-friendly operation. The selection of construction materials for the various parts of the equipment was guided by factors such as availability, cost considerations, and overall efficiency.

Construction of the Equipment

The equipment was fabricated by Inventive Solutions Pvt. Ltd, located in Nashik, Maharashtra, and subsequently installed at the All India Co-ordinated Research Project on Farm Implements and Machinery center, Dr. A. S. C. A. E & T, M. P. K. V, Rahuri. The construction process involved a variety of general manufacturing techniques, including marking, cutting, drilling, grinding, turning, milling, welding, rolling, fastening, bending, and shaping.The experimental setup consists of several key components: the Indoor Circular Soil Bin, Control Panel, Power Transmission Unit, and Wearing Unit (Fig. 1).

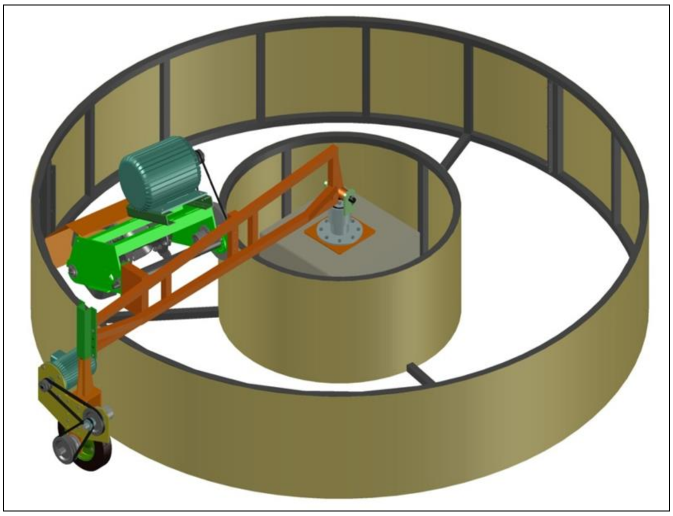

Fig 1: CAD model of experimental setup

Circular Soil Bin

The construction of the circular soil bin involved using a 1.6 mm (16-gauge) thick MS sheet, specifically designed for wear testing of rotavator blades under controlled conditions. The dimensions of the bin were as follows: an outer diameter of 3300 mm, an inner diameter of 1300 mm, and a depth of 625 mm. Consequently, an annular width of 1000 mm was created, providing ample space for operating the wear testing machine (Fig. 2 to Fig. 5).

Fig 2: Circular soil bin

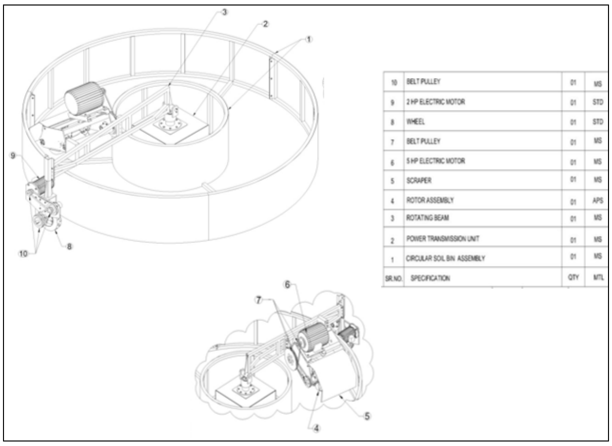

Fig 3: Isometric view circular soil bin

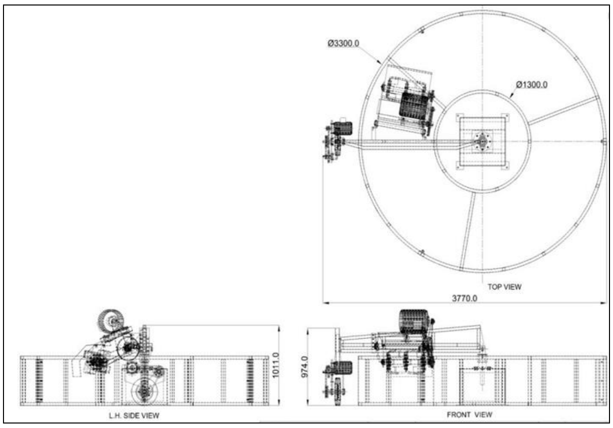

Fig 4: Orthographic view - 1 of circular soil bin

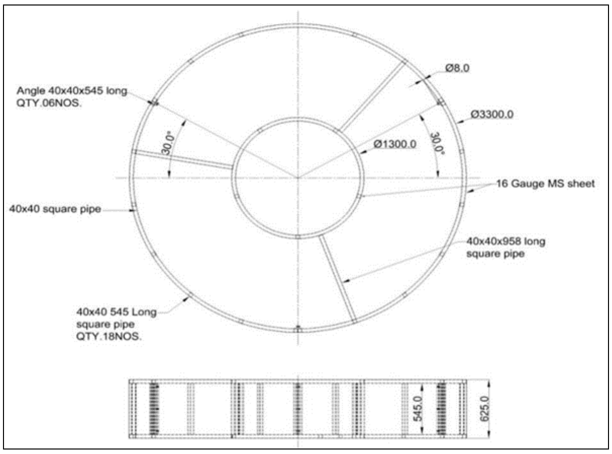

Fig 5: Orthographic view - 2 of circular soil bin

Power Transmission Unit

The power transmission system was established by installing two motors, with one located on the wearing unit and the other on the supporting wheel. A 5 hp motor was affixed to the wearing unit to operate the equipment, featuring speed reduction in a ratio of 1:7. Simultaneously, another 5 hp motor was mounted on the supporting wheel, responsible for rotating the wheel around the circular soil bin. To facilitate the operation of the wearing unit in the abrasive sand, the wearing unit was securely clamped to a 40x40 mm square section horizontal beam measuring 1869 mm in length. A distinctive arrangement involving carbon brushes and slip rings was devised and incorporated onto the horizontal rotating shaft positioned at the center of the circular soil bin. This setup allowed for the transmission of current to the wearing unit, specifically the rotavator machine (Fig. 6 and Fig. 7).

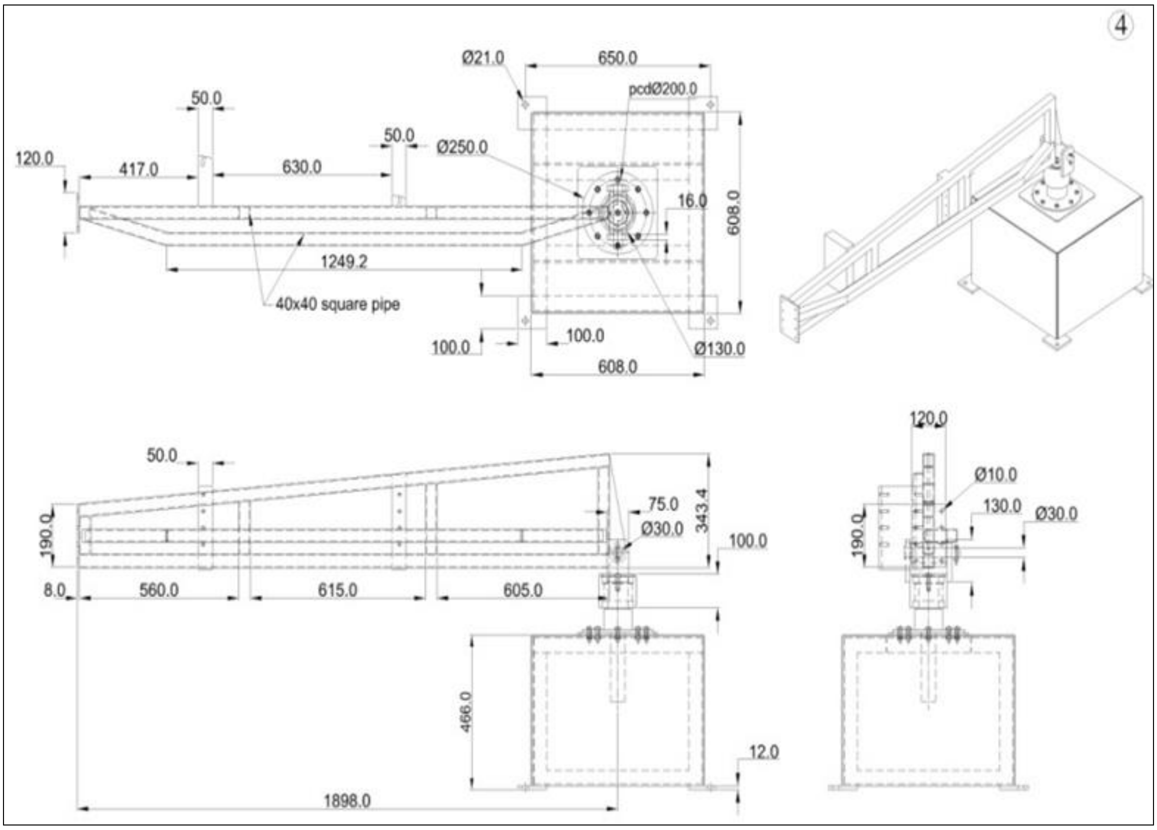

Fig 6: Isometric view – 1 of power transmission units

Control Panel

The control panel was equipped with essential electrical components, including switches, relays, a starter, voltmeter, and a regulator. The regulator, functioning as a current transformer, played a crucial role in adjusting the speed of the 3 hp. motor. This adjustment allowed for achieving the desired operating speed of the wearing unit within the circular soil bin (Fig. 7).

Fig 7: Control panel

Wearing Unit

The wearing unit was custom-designed and fabricated specifically for the experimentation. Resembling a Rotavator, it featured three moving discs (flanges) on which four blades were mounted on each disc, allowing them to rotate on their own axes. A 5 hp motor positioned at the top of the unit provided the necessary power. To reduce the motor's RPM from 1440 to 200, an idle shaft and pulley were incorporated between the motor output and the disc shaft carrying the blades. The speed reduction occurred in two stages through pulley ratios of 1:5 and 1:2. For supplying power to the 5 hp motor, a unique arrangement of carbon brushes and slip rings was devised. This design enabled the transmission of electric power to the 5 hp motor while it rotated around the circular soil bin (Fig. 8).

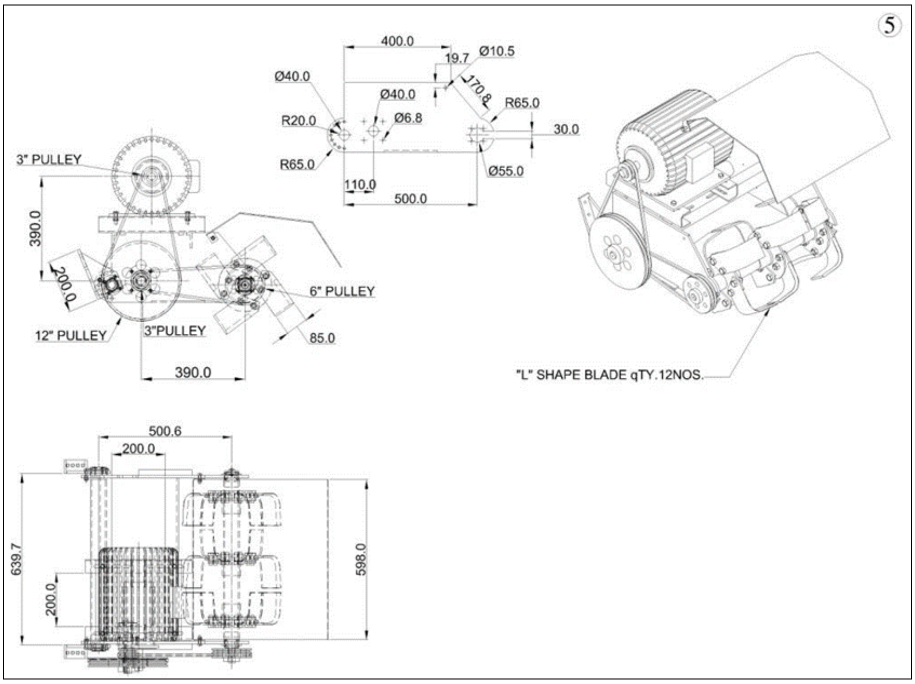

Fig 8: Views of wearing unit

Experimental design

In this study, the influence of steel material on the gravimetric and dimensional wear of rotavator blades was assessed within a circular soil bin, employing sandy soil as the abrasive medium. The test involved affixing rotavator blade (EN8 steel) to the tool frame for continuous testing within the circular soil bin. The sand moisture content was consistently maintained at 8-10 percent throughout the experiments. Operating parameters, including speed of operation, depth of operation, and soil resistances, were set at 0.97 m/s, 140 mm, and 0.10 kg/cm, respectively.

Test Procedure

The circular soil bin was filled with abrasive sand up to a uniform height of 450 mm, ensuring consistency in the abrasive medium. A set of sample blades, manufactured from EN8 material, underwent a meticulous cleaning process involving water and acetone to eliminate dust and corrosion. For gravimetric wear measurement, the blades were weighed using an electronic digital weighing balance with an accuracy of 0.01g. To calculate dimensional wear loss, the width and thickness of the blades were measured using a vernier caliper at nine different sections of each blade. After the initial observations were recorded, the set of sample blades were affixed to the flange of the wearing machine. The wearing test setup underwent thorough checks, including electric connections, carbon brushes, contacts, voltage supply at the control panel, and proper oiling and greasing. The wearing machine was then activated, and the rotational speed of the blades, measured by an optical tachometer, was set at 200 rpm. The blades were adjusted to operate at a specified depth of 140 mm from the surface of the soil. The power transmission unit was switched on, and the wearing unit began revolving at a peripheral speed of 0.97 m/s within the circular soil bin, a speed controlled by a regulator on the control panel. After every 20 hours, the set of sample blades were detached from the wearing unit, thoroughly washed with water, dipped in a dilute acetone solution, and dried. Subsequent observations, including weight, width, and thickness, were recorded. This wear testing process continued for a total duration of 100 hours. The gravimetric wear loss of the blades was determined by calculating the difference in weights before and after the operation. Additionally, the reduction in dimensions concerning width and thickness at each section was documented for dimensional wear analysis.

Data Analysis

Statistical analysis of experimental data was conducted to investigate the abrasion of a rotavator blade crafted from EN8 material. The importance of surface hardening treatment was assessed at a 5% significance level.

Results and Discussion

Local producers and past investigators frequently utilized materials such as medium carbon steel, high carbon steel, En-3, En-8, En-19, En-24, En-42, En-45, and boron alloy steel in the construction of rotavator blades. In the present investigation, medium carbon steels (EN 8) were selected to assess the wear loss of rotavator blades. The metallurgical compositions of the chosen steel are presented below.

Element	C	Si	Mn	P	S	Cr	Mo	Ni	HRC
%	0.410	0.32	0.78	0.043	0.037	0.03	0.003	0.02	11.37

Gravimetric wear: The weight loss of the selected material in abrasive sandy soil exhibited a decrease with an increase in time for the chosen depth and speed. The cumulative wear at a depth of 14 cm and a speed of 0.97 m/s was 98.46 g for the EN8 material over a working period of 100 hours (Fig. 9). This outcome similar with the work of Raval and Kaushal (1990) [19], Kurchania (1997) [12], Mahapatra (2002) [20], Chahar and Tiwari (2009) [4], Kaur *et al*. (2011) [9], all of whom also documented a linear correlation between cumulative wear and the duration of work. The wear rate closely similar to the cumulative wear, measuring at 16.08 mg/ min for the EN8 medium carbon steel rotavator blade at a depth of 140 mm and a speed of 0.97 m/s over 100 hours. The rate of wear demonstrated a direct proportionality to the applied confining stress magnitude. Consequently, the section of the rotavator blade closest to the soil surface and operating at the speed experienced the more wear rate. This finding corresponds with the observations of Kurchania (1997) [12] and Chahar and Tiwari (2009) [4].

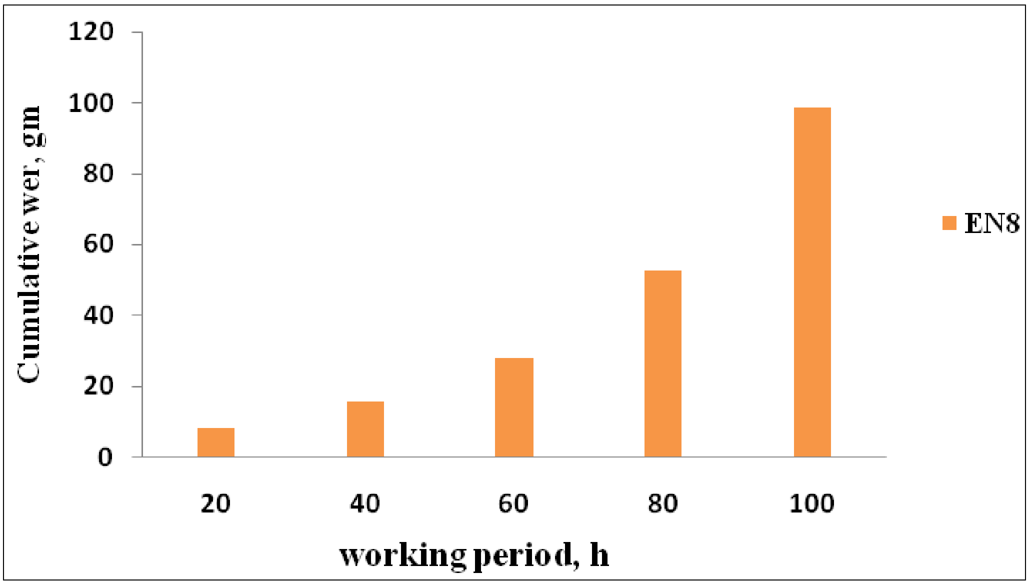

Fig 9: Cumulative wear loss of EN8 blade at different working period

Dimensional Wear

To assess dimensional wear loss, nine distinct demarcations (S0 to S8) at 25 mm distance were established on the blade, and wear measurements were taken for each segment of the rotavator blades. The investigation revealed that the rotavator blade experienced wear predominantly along its width and thickness, with negligible changes in length compared to the width and thickness. It was observed that wear loss in width escalated over time. The cumulative wear loss in width and thickness across all sections of the rotavator blade, at a depth of 140 mm and a speed of 0.97 m/s, measured 22.29 - 30.44 mm and 0.92 - 1.57 mm, respectively, over a 100-hour working period. The width of the rotavator blades exhibited a decrease with an increase in sectional numbers from S0 to S8, with the maximum reduction observed at section S0, representing the tip section of the rotavator blade (Fig. 10 and Fig. 11).

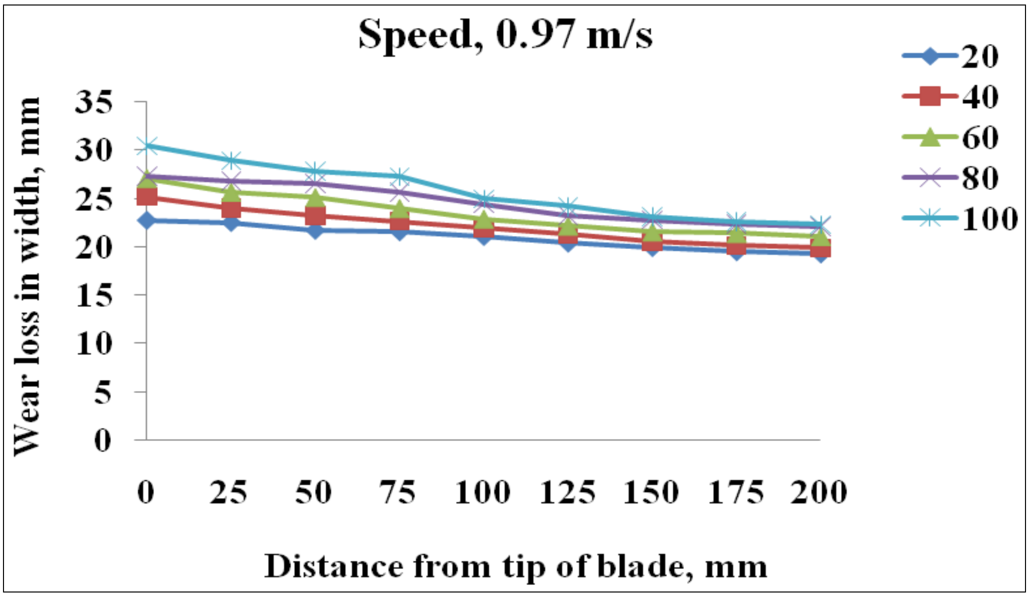

Fig 10: Variation in width of EN8 blade at different working period

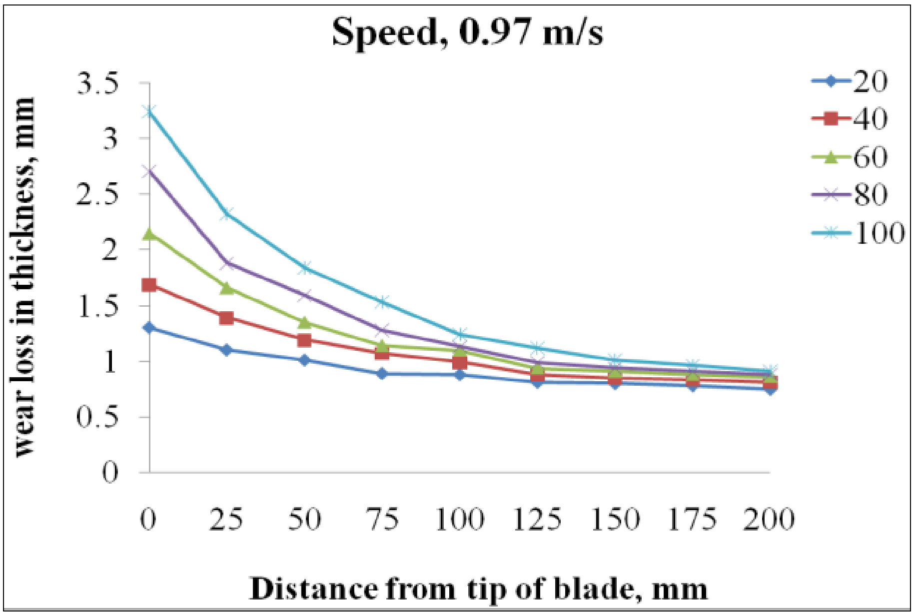

Fig 11: Variation in thickness of EN8 blade at different working period

Conclusions

The control and prevention of wear in agricultural tools hold paramount importance for agro-industrial applications, considering the economic significance associated with the wear of critical components. To facilitate the study of soil-tillage tool interactions, a circular soil bin, designed as an abrasive wear test equipment and has been developed. This design allows for the testing of wear on various soil-engaging implements across different soil types. It serves as a valuable laboratory apparatus for both basic and applied research. In the current investigation, key factors influencing wear, including material composition, tool speed, operating depth, moisture content, soil type, and blade surface hardness, were carefully examined. Notably, a strong correlation was observed between the weight loss (In grams) and dimensional loss (In millimeters) of the rotavator blade in this study.

Suggestions for Further Work

It is advisable to conduct additional research encompassing various soil types and a diverse range of materials to enhance our understanding of the subject.

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