DEVELOPMENT AND EVALUATION OF AN ABRASIVE WEAR TEST EQUIPMENT

by

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DECLARATION

I hereby declare that this work is my own work towards the Master of Science (Agricultural Machinery Engineering) and that, to the best of my knowledge, it contains no material previously published by another person nor materials which have been accepted for the award of any degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

The wear of ploughshares is a major source of economic constraints to local farmers. Most field wear tests have been found to be expensive and time-consuming. Abrasive wear test machines developed in advanced countries are not available in Ghana. The main objective of this study was to develop and evaluate an equipment for testing the abrasive wear of ploughshares. The equipment consists of a circular soil bin, support frame, power transmission system and arm-subassemblies. The equipment was evaluated using a cast-steel ploughshare in soils from KNUST (57.98, 68.9% sand), Wenchi (60.40, 66.26% sand), Ho (70.45, 72.81% sand), Mampong (61.66, 67.33% sand), Akuse (60.74, 64.70% sand) and Akatsi (81.70, 83.02% sand) in Ghana.. As a result of similarity in texture, the wear rate of soils from Akatsi and Ho showed increasing trend with corresponding moisture content while that of Akuse, Wenchi and Mampong showed a reverse trend. In sandy loam and loamy sand soils, wear increases with moisture content while sandy clay loams decrease with increasing moisture content. The study concludes that the wear rate of ploughshare is directly influenced by sand content and the soil type. The pH of the soils were acidic in nature and was not found to influence the wear.

DEDICATION

I affectionately dedicate this work to my wife, Angela, for her love and support.

ACKNOWLEDGEMENTS

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CHAPTER ONE

1. INTRODUCTION

1.1 Background to the Study

Friction and wear of material have accompanied man since his very beginning (Mehulic *et al*, 2005). Materials contact each other through their surfaces. Therefore the surface and subsurface regions are affected by the interactions between two or more bodies. Wear is defined as damage to a solid surface, generally involving progressive loss of material, due to relative motion between that surface and a contacting substance or surface (Gurumoorthy *et al*, 2007). Wear is generally described as abrasive, adhesive or erosive (Allen and Ball, 1996). Among these types, abrasive wear is the most important due to its destructive character (Chattopadhyay, 2001). Abrasive wear is the detachment of the material from surfaces in relative motion, caused by sliding of hard particles between the opposing surfaces; the hard particles normally slide on a softer surface and detach materials from the latter (Harris *et al*, 2002). Wear due to highly abrasive soils have surface damage characterised by scoring, cutting, deep grooving and gouging, and micromachining, caused by soil constituents moving at a relative velocity of about 1 m/s on a metal surface (Ferguson *et al*, 1998).

Soil tillage operations consume large amounts of energy and cause significant wear to tillage tools (Natsis and Petropoulos, 2005). This leads to lower rates of work, decrease in tillage depth, frequent change-over of the cutting edge and as a consequence, higher operation and product costs (Kushwaha *et al*, 1990; Natsis *et al*, 1999). The wear rate of all shares is higher in soils with increasing sand fraction; the main factors affecting wear rate include chemical composition, hardness, and soil physical factors, with sand content and share hardness being the most dominant (Bobobee *et al,* 2007). Agricultural machinery parts working in the soil may be divided according to function into two basic groups, namely soil cutting tools (ploughshares, share of root harvesters, ridger or planters), and soil shaping tools (shoulders and wings of mouldboards, ridgers, soil shoes of ploughs). The wear of parts of the shaping tools has been found to be more severe (Owsiak, 1999). According to Bahyan (2006), in Turkey, there is on average 90–210 g/ ha of wear in a ploughshare, 60–120 g/ ha wear in cultivator sweeps and 30–70 g/ ha wear in harrow tines. This indicates that among these tillage tools, the ploughshare experiences the most wear in soils. If the ploughshare is not replaced when it becomes worn, the plough will not cut into the soil or turn the soil well and ploughing will be very difficult. The wear characteristics of a soil are related to the type of abrasives and stones present (Zhang and Kushwaha, 1994).

For a given tillage tool, the amount of wear decreases when the hardness exceeds that of the soil abrasives and the wear of tillage implements in most soils is caused by the stone and gravel content .The abrasive wear resistance depends on the chemical composition, production history, mechanical properties and microstructure of material and other soil characteristics such as the particle shape, size, the soil strength, density and moisture, and rock and gravel content (Yu and Bhole, 1990). Studies conducted by Baryeh (2001) and Yu and Bhole (1990) tend to agree that wear rate increases with increasing moisture content. Other research conducted by Natsis *et a*l (2008) and Ferguson *et al* (1998) however have shown a contrasting results of a decrease in wear rate with an increase in moisture content.

1.2 Significance of the Study

Agriculture still remains the backbone of Ghana's economy. The sector employs 56% of the population and contributes 33.7% of the Gross Domestic product (CIA, 2011). Thus any factor which leads to inefficiency in this sector can have serious influence on the economic well-being of the country. Farm machinery are used on the farm to reduce drudgery and increase food production. However, farmers and equipment operators often complain about the high wear rate of ground tools on farm machinery (Bahyan, 2006). They are faced with the recurring downtime, labour, and replacement costs of exchanging the worn out ground-engaging components (Bobobee *et al*, 2007). Soil engaging parts wear as a result of abrasion from the soil and as a result of this, tillage implement are designed in such a way that ploughshares and tines are easily changed. The ploughshare wear does not only affect its working life but directly changes its initial shape which is one of the most important factors influencing ploughing quality (Horvat *et al*, 2008). Rapid ploughshare wear has been identified as a major constraint facing farmers in Ghana (Bobobee, 1999).

The economy of Turkey loses 4.4 million dollars annually due to wear of tillage tools (Bayhan, 2006). Other research indicates that Canada's economy also loses around 3.9 billion dollars annually while South Africa and Australia are estimated to lose several millions of dollars due to the wear of tillage tools (Bayhan, 2006; Yu and Bhole, 1990; Ferguson *et al* 1998; Quirke *et al*, 1988). The determination of the wear rate of tillage tools is necessary because it seriously affects production planning, tillage quality and the cost of agricultural produce.

According to Tylczak *et al*,(1999), most field wear tests have been found to be expensive and time-consuming. As a result of this, many soil bins (and machines) have been developed with varying degrees of success to model the conditions found in the field. The first soil bin facility for agricultural work was developed by Goerge Kuehne in Germany in 1914 and since then, a number of such soil bins have been developed and installed all over the world (Al-Janobi and Eldin, 1997). These are located in research centres as well as companies that manufacture agricultural equipment for basic and applied research. However, none of these facilities have been developed in Ghana. This necessitated the need to develop a wear test equipment for carrying out research in the laboratory.

1.3 Aim and Specific Objectives

The main aim of this study was to develop and evaluate an abrasive wear test equipment. The specific objectives of the study were:

1. To design and construct an abrasive wear test equipment.
2. To compare the wear of cast-steel ploughshare in soils from six different sites in Ghana.

3. To investigate the influence of moisture content on the wear of cast-steel ploughshare.
4. To evaluate the influence of pH on the wear of cast-steel ploughshare.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Definition of Wear

Tribology, the study of wear, friction and lubrication is as old as human culture yet it is considered as the Science of the future (Stachowiak, 2007). Tribologists study causes and mechanisms of wear in daily applications (Soyjaudah and Ramasawmy, 2001). According to Gurumoorthy *et al* (2007), wear may be defined as damage to a solid surface, generally involving progressive loss of material, because of relative motion between that surface and a contacting substance or substances. Soyjaudah and Ramasawmy (2001) also defined wear as the progressive loss of material from the surface of a body due to friction. According to Juhani *et al* (2006), wear is one of the most common causes of failure of engineering materials.

2.2 Types of Wear

Wear has been described by a multitude of terms and interpretation depending on the situation. However, there are three major categories of wear into which most situations can be included: adhesive, erosive and abrasive wear (Allen and Ball, 1996).

2.2.1 Adhesive Wear

According to Harris *et al* (2002), adhesive wear occurs when wear particles are formed due to interaction between the rubbing surfaces. It could also be named scuffing, scoring, seizure and gulling due to the appearances and behaviour of the worn surface.

Adhesive wear is often associated with severe wear but its role in mild wear conditions is unclear. Another form of adhesive wear can be termed impact wear where material is lost due to repeated high energy impact conditions (Allen and Ball, 1996). This is illustrated in fig. 1 below after Poeton (2011).

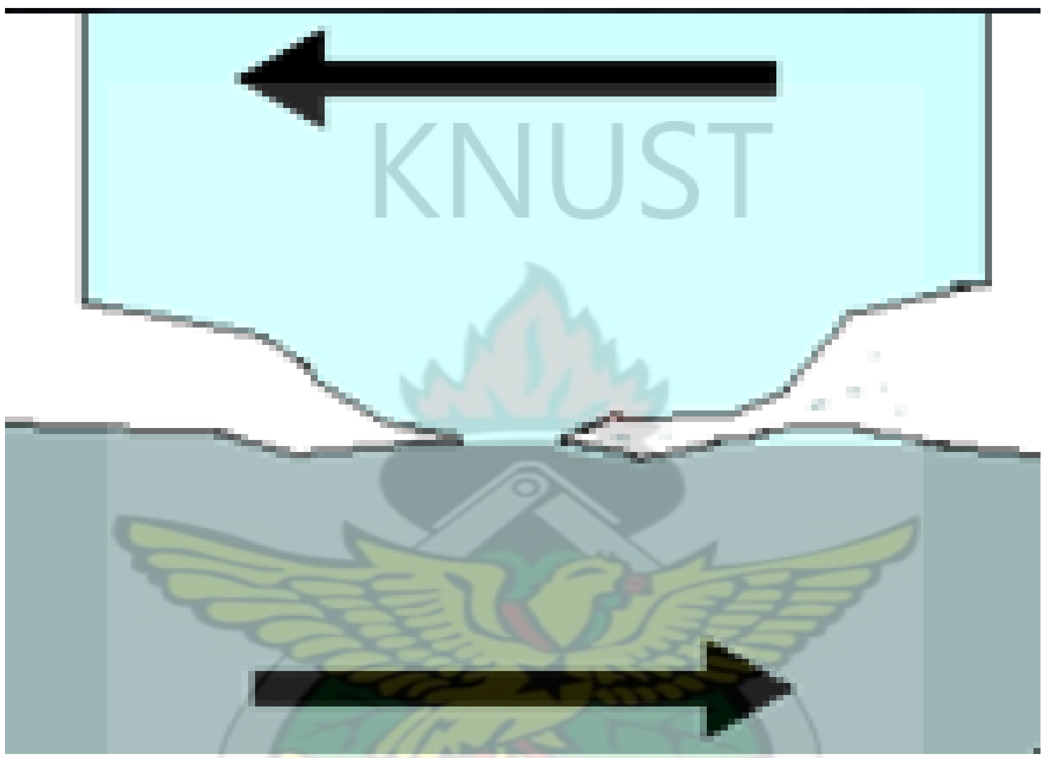

Fig. 1: Adhesive wears (Poeton, 2011)

2.2.2 Erosive Wear

Baryeh (1997) attributed erosive wear to the action of numerous small particles, which impinge on a surface, such as sand blasting caused by severe plastic deformation and subsurface damage, which eventually creates loose wear particles. It can have a serious deteriorating effect in engineering systems, including pipelines and valve handling gases, hydraulic systems, aerospace components and liquid impellers. The variables affecting the severity of erosion can be interactive and include particle size, mass, shape and velocity together with the flux of erosive particles and their angle of impact (Allen and Ball, 1996). Fig. 2 shows how erosive wear occurs (Poeton, 2011).

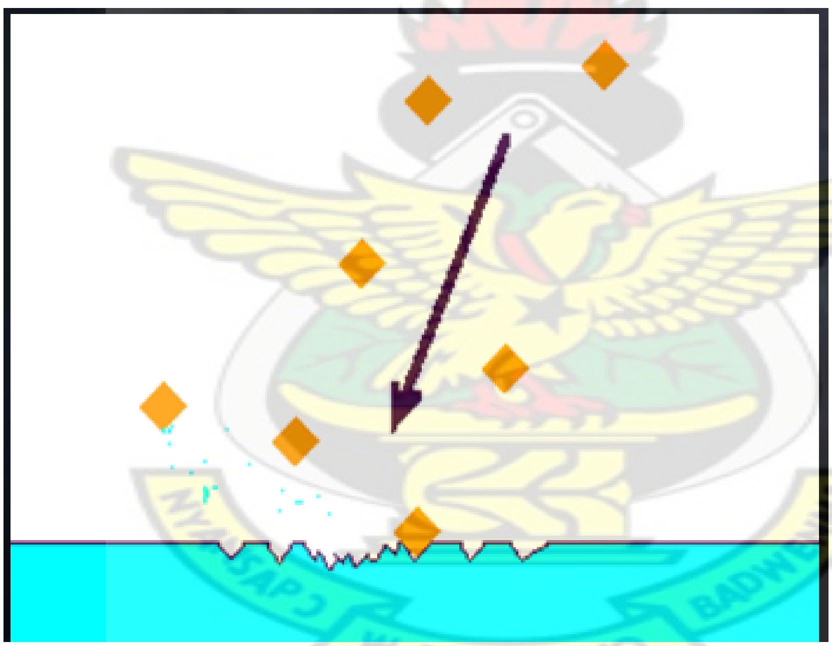

Fig. 2: Erosive wear (Source: Poeton, 2011)

In high angle erosion, much of the energy is expended in deformation of the surface, which requires a resilient coating. On the other hand in low angle erosion, the action is more akin to abrasion and cutting. It requires a hard surface to reduce the wear rate. Fig. 3 shows how low and high angle erosion occurs (Poeton, 2011).

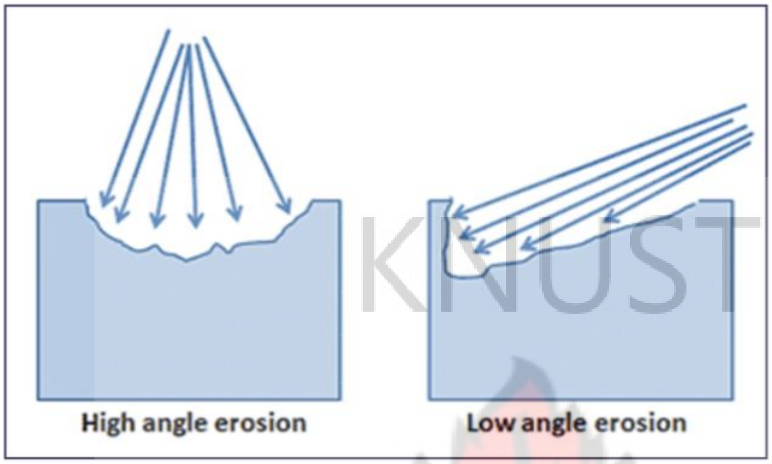

Fig.3: High and low angle Erosion (Source: Poeton, 2011)

2.2.3 Abrasive Wear

Abrasive wear occurs when the sharp materials produce loose grains that have a higher hardness than the surface subject to the abrasive wear (Harris *et al*, 2002). Abrasive wear is usually divided into two types: two-body and three-body abrasion. The situation where exactly two bodies are involved in the interaction is known as two-body abrasion. Two-body abrasive wear is caused by the displacement of material from a solid surface due to hard particles sliding along the surface. Two-body abrasive wear is a complex process often involving high strain and plastic deformation and fracture of micro volumes of the material, which might be described as the removal of discrete surface by a harder substance, which tends to gauge, score, or scratch. Two-body abrasive wear is undesirable due to high wear rates, dramatic surface damage, and activation of other wear mechanisms (Chattopadhyay, 2001).

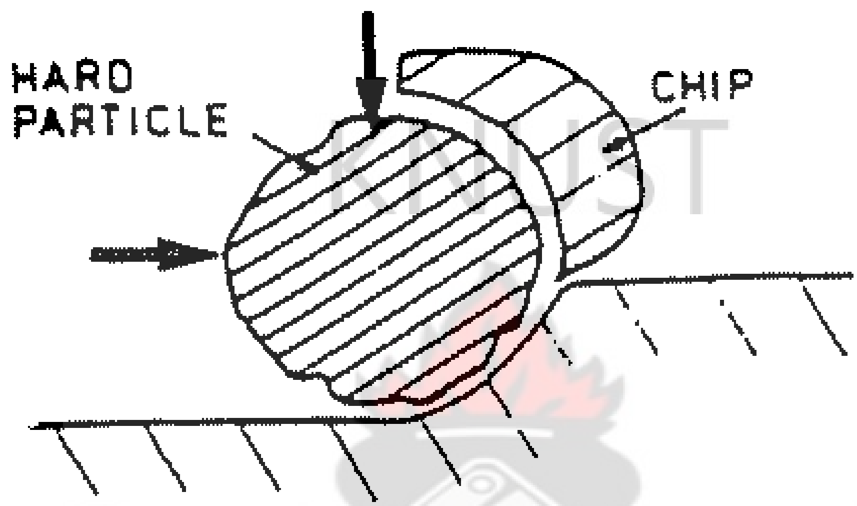

Fig. 4: Two body abrasive wear (Source: Hutchings, 1992)

However, in three body abrasion (fig. 5), the grits are free to roll as well as slide over the surface (Mohan *et al*, 2010; Poeton, 2011). Three-body abrasive wear is ten times lower than the two-body abrasive wear since it has to compete with other mechanisms such as adhesive wear (Chattopadhyay, 2001).

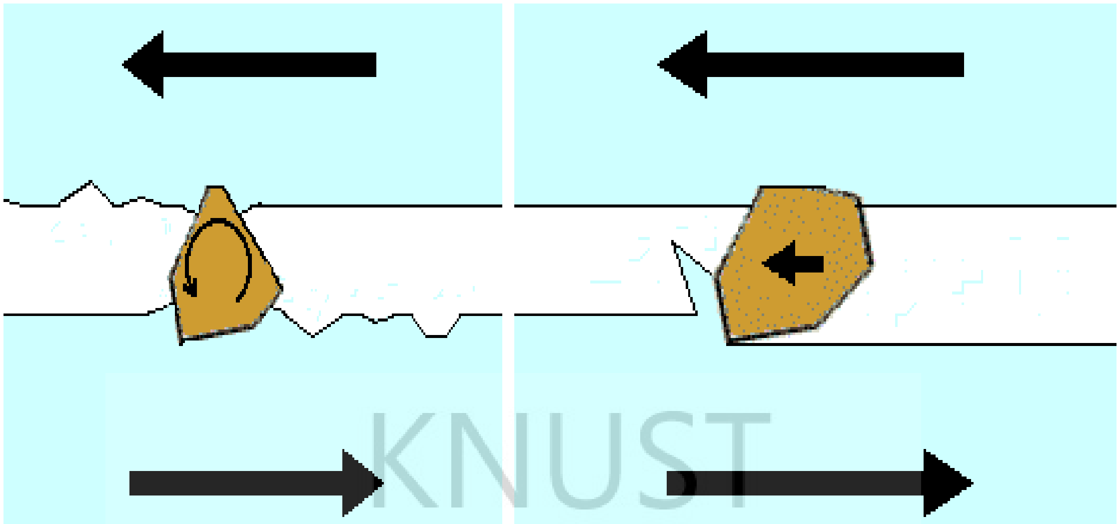

Fig.5: Three body abrasive wear (Source: Poeton, 2011)

The wear coefficient is determined mainly by the abrasive geometry, the effective sharpness of the abrasive, and to a smaller extent by the lubrication which determines the ease with which wear debris can be removed from the sliding interface. Abrasive wear only occurs when the sharp materials produce loose grains that have a higher hardness than the surface subject to the abrasive wear (Harris *et al*, 2002). Studies on the wear of elements subjected to the impact of natural abrasives are carried out at many research centres, but the abrasive wear resistance of material is usually determined under laboratory conditions and includes selection of adequate grades of steel (Owsiak, 1999). The relative abrasive wear of the commercial tillage tool share can be tested in the soil bin and it is related to both hardness and chemical composition of the material (Bayhan, 2006).

2.3 The Mechanism of Abrasive Wear

Since abrasive wear is caused by the presence of hard particles which are between or embedded in one or both surfaces (Yu and Bole, 1990), two forces come into play:

1) The load which acts normal to the surfaces in contact,

2) A force exerted by the machine in the direction of motion which overcomes friction, adhesion and abrasion.

These two forces combine to subject the surface and the sub-surface of the mating materials to stresses. This may have the following effects:

a) to work-harden the softer surface or both surfaces,

b) to cause plastic deformation of the softer of the two materials, particularly when overcoming adhesion,

c) when junctions occur, to dislodge particles from the more wear-vulnerable of the two surfaces,

d) in the presence of abrasive material, grooves are ploughed into the softer material (Meigh, 2000).

2.4 Wear of Tillage Equipment

Wear will occur in any situation where materials with different hardness are in contact during relative motion. The harder surface deforms that of the softer material (Kragelskii 1965). It is this very condition which exists during tillage. Soil tillage involves large amounts of energy necessary to cut, break down, invert soil layers, reduce clod size and rearrange aggregates, and causes significant wear to tillage tools (Formato *et al*, 2005 ; Hernanz and Ortiz-Canavate , 1999; Horvat et al, 2008). A major portion of this energy and wear loss can be attributed to the friction between the soil and tool surface (Kushwaha *et al*, 1990; Kato, 2000). In this process abrasion with hard soil particles is the dominant influence on the tillage tool wear (Heffer, 1994 ; Zum Gahr, 1998). The wear of soil tillage tools by abrasion of soil particles highly corresponds to the mechanical and microstructural properties of the material, which the tools are made of and also the soil texture as well as the working conditions such as the cultivation depth and the soil moisture content (Owsiak, 1997 ; Natsis, 1999; Horvat *et al*, 2008).

The life of agricultural machines and devices depends mostly on their style, features, type of usage and maintenance and repair works of processing components, which are usually because of breaking and wear (Tugrul and Icoz, 2005). Owsiak (1999) found that the operational reliability of agricultural machines designed for work in the soil depends mainly on wear and life of their soil engaging implements. Most agricultural operations are carried out in the field and are subject to wear and friction. According to Bahyan (2006), farmers and equipment operators often complain about the high wear rate of tillage tools, which result in recurring labour, downtime and replacement costs of exchanging components. A study conducted by Tugrul and Icoz (2005) found the wear of ploughshare, cultivator and harrows to be 150 g/ha, 135 g/ha and 90 g/ha, respectively.

Unlike typical wear studies of metal-metal contact, tillage wear involves low stress abrasion, much harder abrading particles, and an absence of lubrication (Yu, 1991). For this reason, wear studies of tillage tools cannot be carried out in the same manner as other wear experiments. To increase the intricacy of the tillage wear scenario, soil texture (Yu, 1991), soil particle angularity (Swanson 1993), and soil moisture (Zhang 1992), all of which can vary widely must be considered.

2.5 Factors influencing the wear of soil engaging tools

Wear caused by hard soil particles is a major problem associated with agricultural tillage equipment. This kind of wear is abrasive in nature and may have a damaging effect on the cutting edge of the tool. Abrasive wear is the most general situation in the wear of metals and is a commonly encountered degradation process in machines and components used in the mining, power generation and agricultural industries (Allen and Ball, 1996). Wear on the parts of a plough body, more systematically, depends on:

(i) the wear resistance of the plough parts based on their thermal processing and shape;

(ii) the tillage conditions, as plough area (or time), plough speed and tillage depth;

(iii) the normal forces between the soil and the surfaces of the plough area;

(iv) the proportion, hardness, sharpness and shape of soil particles;

(v) the density and mechanical properties of the soil (hardness, shear strength and brittleness);

(vi) the moisture content of the soil (Natsis *et al*, 2008).

Generally, abrasive wear is supposed to occur on a soft metal surface abraded by hard and sharp particle. Wear of soil-engaging components occur because the material used is softer than the natural abrasive soil, so that severe scratches are caused on the tools, resulting in the blunting of newly sharpened edges (Natsis *et al*, 1999). According to

Natsis *et al* (2008), the rate of wear of tillage tools depends on the soil texture. In support of this, Scheffler and Allen (1988) reported that the surfaces of steels abraded in sandy soils were relatively smooth and uniform as compared to clay soils. This is because, in clay soils, the abrasive particles are more firmly held *in situ*. They found out that the wear scars of the steel in stony soils were found to be deep and gouging where material had to be torn from the surface.

The hardness of the materials used for the manufacture of the implement is also a major factor in the determination of wear in soils. The chemical composition and hardness of the material used are some main factors affecting the wear rate of ploughshares. Bobobee *et al* (2007) identified hardness as one of the most dominant factors in this regard and also reported that the amount of wear decreases when the hardness exceeds that of the soil abrasives.

Another factor influencing wear is soil moisture content. According to Miller (1984), the effect of moisture on the wear rate of tillage tools is dependent on soil type, being different for sandy soils than with clayey soils. Natsis *et al* (1999) also reported that for loam and clay, as the moisture content increases, wear decreased, while for sandy soils, wear increases as moisture content increases. This is in agreement with reports by Yu and Bhole (1990) and Baryeh (2001) of an increase in wear rate in sandy soils with increase in moisture content. Natsis *et al* (2008) report that the soil bending and cutting resistance markedly reduce with an increase in moisture content more than 12%, which results in consequent wear reduction. Under dry conditions such as 2% (db), Ferguson *et* *al* (1998) observed shares wore at a rate of 4.25 times faster than in wet conditions (18% mc db) with an average life of 9 km compared with 38.4 km, for wet conditions. Ferguson *et al* (1998) and Miller (1984) found that soil moisture content and soil aggregate affect cultivator shares in some soils in Australia. Fig. 6 shows the relation between the chemical compositions and the wear rate of a cast-steel ploughshare. The correlations show greater consistency among the elements and the wear rate. Carbon and hardness are usually very tightly correlated and for this reason, carbon is used as proxy for hardness. In all, carbon in the form of carbide negatively influences wear (Bobobee *et al*, 2007). Carbon has a major effect on the properties of steel and is the primary hardening element in steel as a result, increasing the carbon content decreases the ductility. Manganese and Phosphorus also contributes to hardness and strength while phosphorus and sulphur tend to decrease the ductility and notch impact toughness of steel (Yazici, 2011)

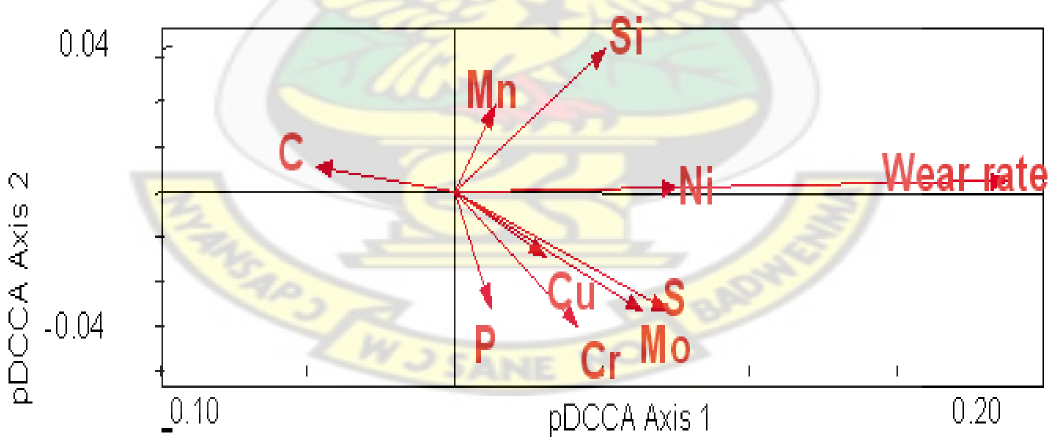

Fig.6: Ordination diagram displaying the first two axes of the pDCCA for the share chemical composition and wear rate (Bobobee *et al*, 2007).

Fig. 7 shows the effect of share hardness and soil physical parameters on share wear rate. The wear rate is more strongly correlated with the sand and bulk density than with moisture content and cone index. This implies the higher sand fraction and bulk density and to a lesser extent moisture content and cone index affected share wear rate (Bobobee *et al*, 2007).

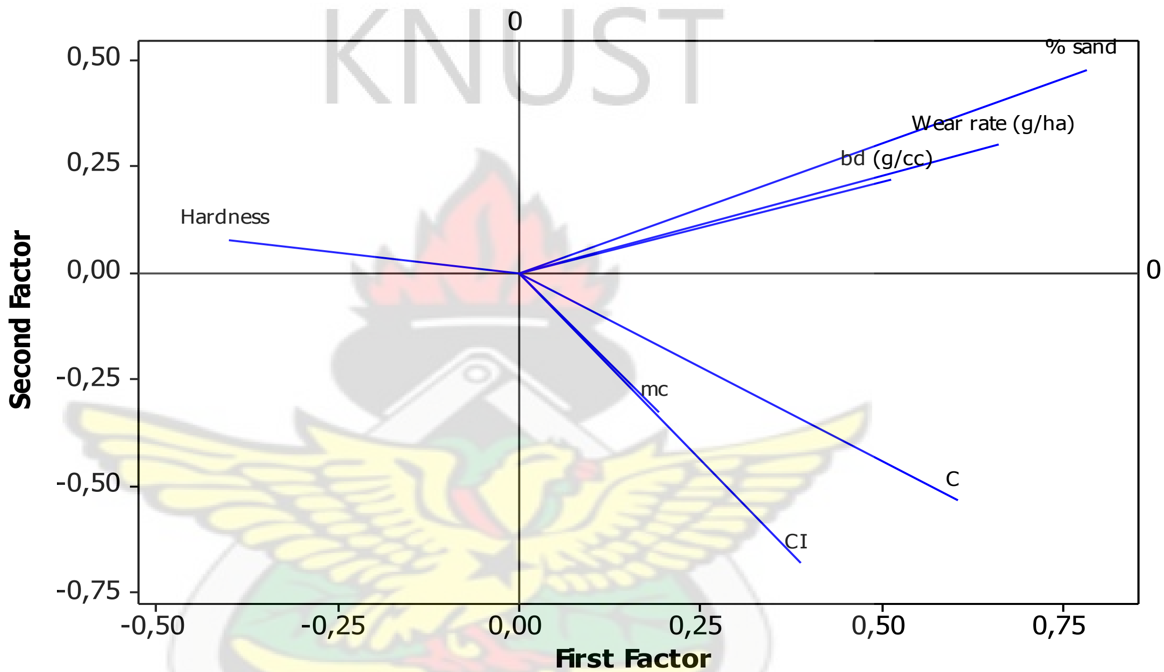

Fig. 7: PCA loading plot of effects of share hardness and soils physical parameters on share wear rate (Bobobee *et al*, 2007).

2.6 Standard Laboratory Abrasive Wear Tests

There are several machines designed to test how two or more surfaces in contact move relative to each other under controlled conditions. They are sometimes called test rigs. Wear testing rig is a device used to simulate wear in the laboratory that enables the recreation of the real life conditions under which wear occurs and the observation of their effects on samples of commonly used or newly designed materials and lubricants (Soyjaudah and Ramasawmy, 2001).

Abrasive wear tests are normally grouped into high-stress or low stress abrasion. In high-stress abrasion, the crushing strength of the abrasive particles is exceeded at typical concentrated contacts so that they are broken up during the wear process. In low-stress abrasion, the particles remain essentially intact – pipe work, hoppers and conveyors carrying solid particulates are typically subjected to low-stress abrasion (Williams, 2005).

2.6.1 Pin-on-disc abrasive wear test

The pin-on-disc test is generally used as a comparative test in which controlled wear is performed on the samples to study. The volume lost allows the calculation of the wear rate of the material. Since the action performed on all samples is identical, the wear rate can be used as a quantitative comparative value for wear resistance. Fig.8 shows a pin-on disc wear testing machine (Mell and Begin, 2010).

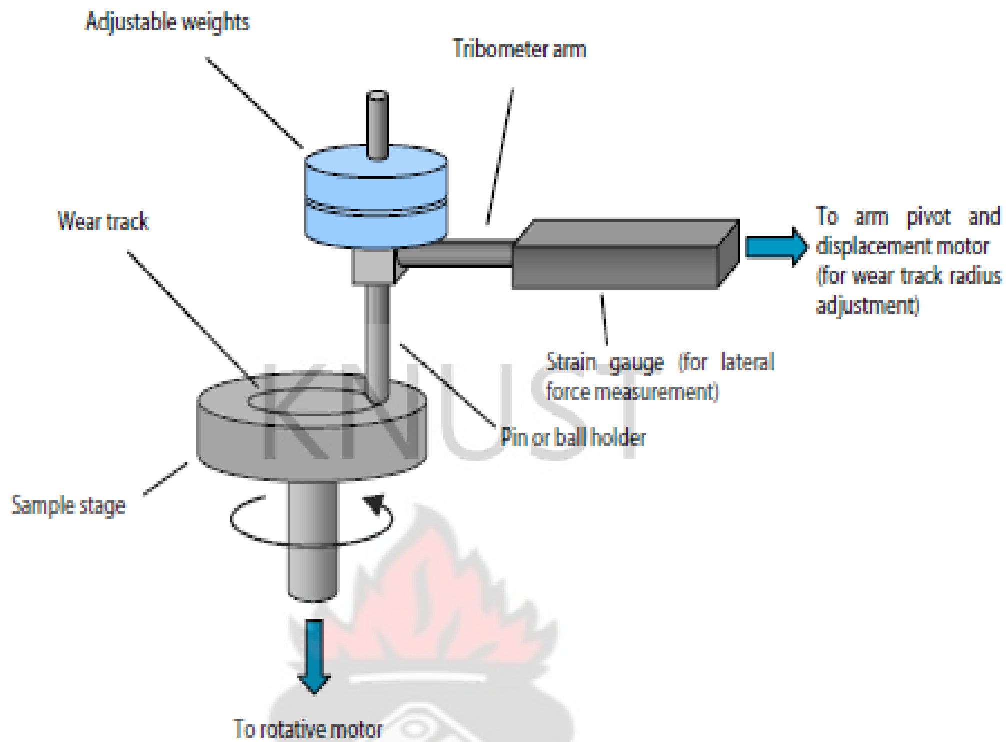

Fig. 8: Pin-on-disc wear testing machine (source: Mell and Begin, 2010)

2.6.2 Pin-on-drum (POD) abrasive wear test

The pin-on-drum abrasive wear test (POD) involves high-stress, two-body abrasive wear. In this test, one end of a cylindrical pin specimen is moved over abrasive paper with sufficient load to abrade material from the specimen and crush the fixed abrasive grains. This test simulates the wear that occurs during crushing and grinding of ore in which the abrasive (the ore) is crushed. The pin also rotates while traversing. This ensures that the pin always contacts fresh abrasive. This is a high-stress abrasion test, as the load is sufficient to fracture the abrasive particles (Hawk *et al*, 1999).

In this test, a rotating 6.35 mm test pin is pressed against 500 mm diameter drum with a load of 66.7 N. The drum is covered with an abrasive cloth, in this case a 150 mm mesh garnet. The drum is then rotated and the pin translated down the axis of the drum (in a helical fashion) so that fresh abrasive is constantly encountered. The test duration is selected to achieve at least 40 mg of specimen mass loss. The mass loss is then converted into a volume loss per unit distance description of the test apparatus (mm^3/m). Fig.9 is a schematic diagram of a pin-on-drum set-up (Tylczak *et al*, 1999).

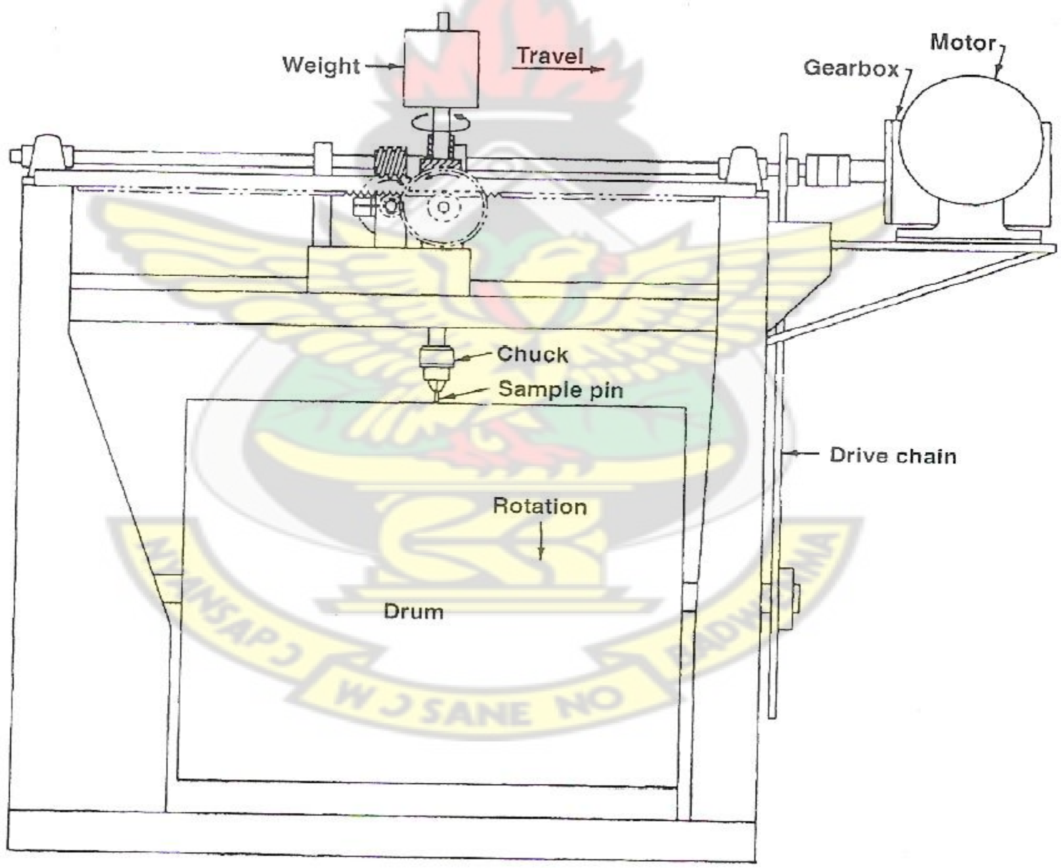

Fig.9: Schematic diagram of pin-on-drum apparatus (source: Hawk *et al*, 1999).

2.6.3 Dry sand rubber wheel (DSRW) test

This test is used to rank the abrasion or scratch resistance of materials to silica sand. It is a low-stress abrasion test used to simulate three-body abrasive wear and is used for dry wear conditions. In operation, sand particles are trapped between the specimen and a rubber wheel and dragged along as the wheel rotates. The specimen is held against the wheel with a contact force. Because this type of wear is slow, field trials alone would be too slow for evaluating new materials. The DSRW abrasion test gives a reasonable correlation with the field tests. Even before the test became an ASTM standard (G65-81) in 1980, it had been used by a number of laboratories for many years (Hawk *et al*, 1999).

This test consists of a rubber wheel of 228mm diameter and 12.7 mm thick, that turns at 200 rpm. A curtain of 50/70 mesh rounded silica sand flows between the rubber wheel and the rectangular test specimen, 25 x 75 x 12 mm. The specimen is held against the rubber wheel using a lever arm with a force of 130 N (Tylczak *et al*, 1999).

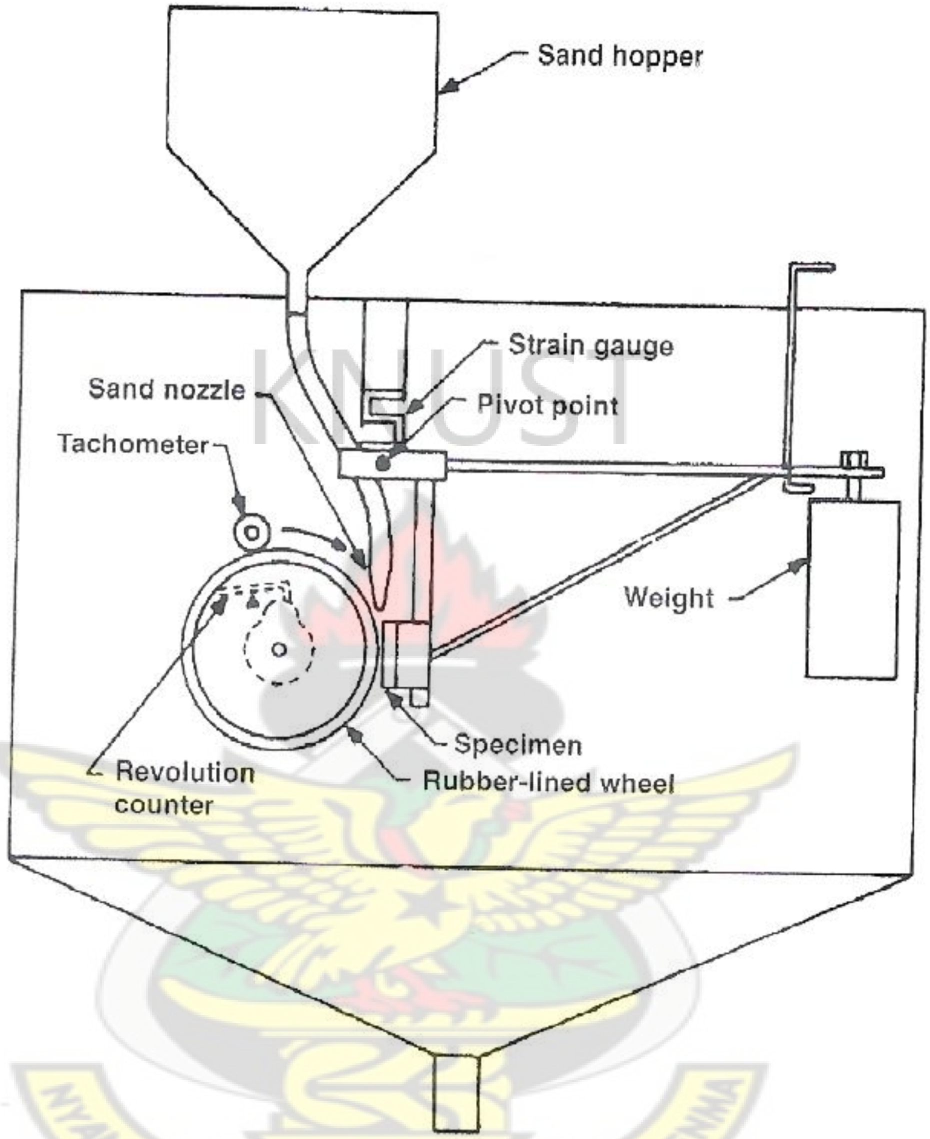

Fig.10: Schematic representation of DSRW wear tester (Source: Hawk *et al*, 1999)

2.7 Soil Bins used for Abrasive wear test of tillage tools

Field experiments can be time consuming (Tylczak *et al*, 1999) and sometimes difficult to repeat under the same soil conditions. This led to the development of the first soil bin facility in 1914 by George Kuehne in Germany. Controlled studies are possible in soil bins where the operating variables are monitored and the experiment closely monitored to eliminate problems associated with field testing. One distinguishing characteristic of such facility is the component which is in motion. The soil bin can be stationary while the soil processing and tool units are movable and vice versa (Al-Janobi and Eldin, 1997).

2.7.1 Indoor Soil Bins

The Department of Agricultural and Bioresource Engineering at the University of Saskatchewan has been in the forefront as far as the development of soil bins for soil-tillage tool interaction studies is concerned. Fig.11 shows the layout of a circular abrasive wear tester installed in the Department. The tester consists of an annular soil bin and soil conditioning equipment. The tillage tool travels around the annular soil bin followed by a scraper, a sheep's foot packer, and a smooth packer spaced at 90 degrees intervals. The outside diameter of the soil bin is 3.05 m, the inside diameter is 1.83 m and the height of the soil bin is 0.61 m. The annular soil bin has four arms fixed to a main vertical shaft driven by a hydraulic power system. The length of each arm is 1220 mm and the power system consists of a 10 kW electric motor driving a variable output hydraulic pump. The angular speed is regulated by adjusting the flow rate of the hydraulic pump (Zhang and Kushwaha, 1994).

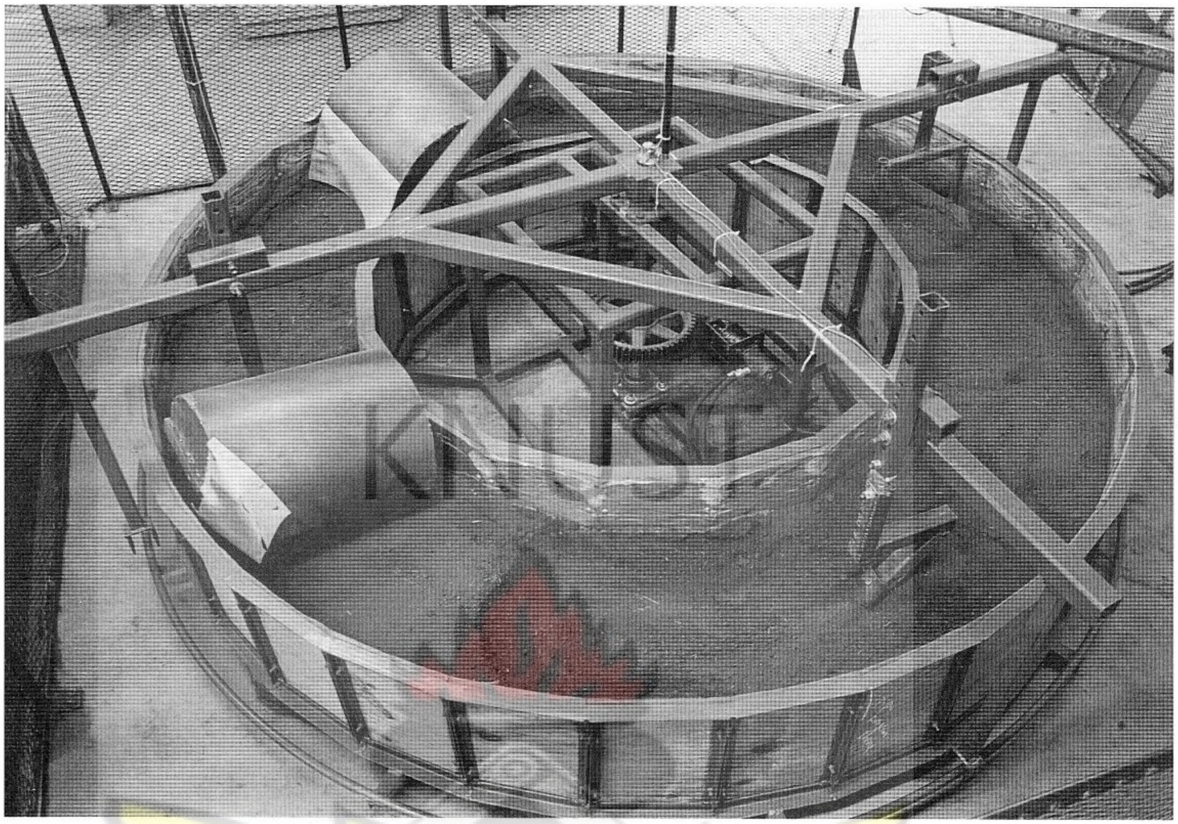

Fig. 11: Circular soil bin at the University of Saskatchewan (Source: Zhang and Kushwaha, 1994)

Figure 12 shows a new circular soil bin at the University of Saskatchewan installed in a laboratory for soil-tillage tool studies. It pulls a tillage tool sample through a soil medium which very closely imitates field conditions. A set of sweeps and discs follow the sample and move the soil back to the middle of the working path, and a pair of packer wheels compact the soil for the next pass of the samples. The carriage is powered using a 50-hp three-phase electric motor which runs a variable flow hydraulic power unit which is controlled with electric solenoids. The hydraulic power unit serves to operate a drive train from a self-propelled combine which rotates the carriage of the soil bin. The inner and outer diameters of the bin are 2.3 and 4.3 m respectively and at a working diameter of 3.2 m and the working speed range is 0 to 9.7 km/h. The soil bin was designed for testing complete ripper points and the layer of soil is approximately 0.6 m deep. The bin is also designed to allow the mechanism to rotate in either direction to eliminate the effects of a circular motion. A magnetic pick up connected to a data logger allowed the number of revolutions of the tool carriage to be counted for tool travel distance measurement (Graff *et al*, 2007**).**

Fig12: New Circular soil bin at the University of Saskatchewan (Graff *et al*, 2007)

Figure 13 shows the general arrangement of another indoor rectangular soil bin testing facilities. Unlike other facilities described above, this type of soil bin is rectangular in shape and has a moving carriage that moves on rails using two chains above a soil channel. Forward and reverse movement of the carriage is made possible by using a chain drive system. This chain runs from the drive sprocket at one end and an idler sprocket at the other extreme end with two 24m chains located between these two ends; forward and reverse movement of the carriage are made possible. For measuring the horizontal force, vertical force, depth and other testing parameters, it can be equipped with various transducers. Data acquisition system is able to receive and control the information, measurement of signals in real time, display the information on a monitor screen and finally record the information into a storage medium in real time (Mardani *et al*, 2010).

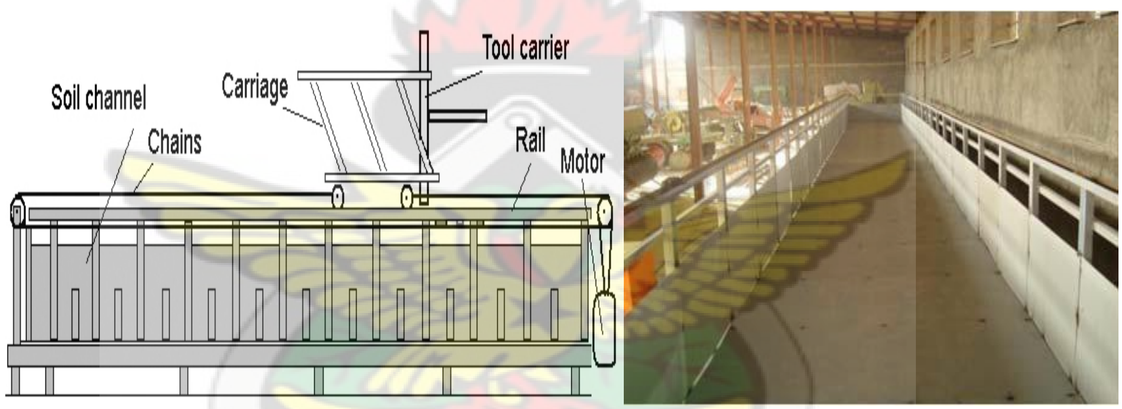

Fig. 13: Rectangular soil bin (Source: Mardani et al, 2010)

2.7.2 Outdoor Soil Bins

Some soil bins are prepared and installed in open places and this is normally employed in a situation where the experiment needs more space. Manuwa *et al* (2011) give a description of one such outdoor soil bins at the Federal University of Technology, Akure (FUTA), Nigeria. The soil bin facility consists of the following major components: the soil bin; the soil fitting equipment- compaction roller, levelling blade; tool carriage and tool carriage sub frame, load cells. The soil bin facility is equipped with a soil bin with a dimension of 48.0 x 1.5 x 1.2 m in length, width and height, respectively. The walls of the soil bin were constructed with concrete blocks. The blocks were clad with bin wall panels for better reinforcement, rigidity, and efficient and effective behaviour of bin walls in service. The bin wall panel was fabricated from mild steel plate 8 mm thick, inverted L-section 150 x 1050 x 2400 mm, with drilled holes for installation.

The steel rails (two in number) run parallel to each other along the whole length of the bin. They are made from steel angle sections 150 x 150 x 10 mm and installed on concrete shoulder of the bin by means of drilled holes (on the railings) 12 mm diameter countersunk at 60 degrees at 1.0 m intervals. The implement carriage was designed to run on the railings whose horizontal surface width was compatible with the running wheels of the implement carriage (Manuwa *et al*, 2011).

Fig.14: An outdoor soil-bin facility being used to carry out an experiment (Source: Manuwa *et al*, 2011)

Fig. 15 also shows an outdoor soil bin which is 1.5 m wide, 15 m long, and 0.6 m deep as described by Liu (2005) and Liu *et al* (2007). The soil bin is located in the Department of Biosystems Engineering at the University of Manitoba, Canada. In carrying out experiment in the soil bin, sweeps are mounted on the carriage of the soil bin. The tillage depth and speeds are set to suite the experiment.

Fig. 15: Tool carriage used for soil bin experiment at the University of Manitoba (source: Liu *et al*, 2007).

2.8 The economics of Abrasive Wear

The rapid wear of soil engaging machine parts is responsible for most of the idle time for maintenance, as well as expenditures for repairs and manufacture and the manufacture of spare parts (Zhang and Kushwaha, 1994). For example Baryeh (2001) reported that the wear of hoes leads to frequent stoppage of work to resharpen or replace them. This further leads to loss of time, especially during peak seasons and consequently, to low yield and financial loss. Bobobee *et al* (2007) also reported that wear of ploughshares leads to frequent work stoppages for replacement and contributes to high costs in parts, downtime and labour estimated to be several millions of dollars annually. Soil tillage operations consume large amounts of energy and cause significant wear to tillage tools. The latter results in deterioration of the overall performance of the plough i.e. higher energy losses demanding higher fuel consumption, lower rates of work, decrease in tillage depth, time consuming changeover of the cutting edge and as a consequence, higher operation and product costs (Kushwaha *et al*, 1990; Natsis *et al*, 1999; Natsis and Petropoulos, 2005).

Increasing the service life of machines has become one of the important challenges of technological progress. The problem of increasing durability is inseparably linked with a study of friction and wear patterns of machine parts in operation and the development of the basis of the durability rating of machine parts and machines (Zhang and Kushwaha, 1994). In the Australian industries wear is considered as something inevitable i.e we have to live with it, and its cost simply included and budgeted for (Stachowiak, 2007). A strategy for tribology in Canada (NRCC, 1986) stated that the total annual loss in the agricultural sector due to friction and wear amounts to $1.26 billion, of which wear accounts for nearly $960 million. The share of tillage operations is estimated to be more than $32 million and the potential savings resulting from reducing friction and wear in agricultural operations would amount to $104 million per year and reducing wear by improving wear performance in agricultural operations would amount to $223 million per year (Zhang and Kushwaha, 1994). In Turkey, the estimated total loss due to wear of tillage tools sums up to $4.4 million per year (Bahyan, 2006).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Sites for taking soil samples

Soil samples were taken to a depth of 40cm from six places (KNUST, Mampong, Wenchi, Ho, Akatsi and Akuse) as shown in Fig. 16. KNUST(Anwomaso research farm) is located at latitude 6°41'56.75"N, longitude 1°31'25.85"W and altitude 274 m above sea level, Mampong at latitude 7° 2'19.84"N, longitude 1°23'48.60"W and altitude 401 m above sea level , Akuse has a latitude of 6˚6’0” N, longitude 0˚80’ 0” E and altitude of 67 m above sea level and Ho is located at latitude 6° 36' 0" N, longitude 0° 28' 0" E and altitude 158 m above sea level. All these towns are found in the semi-deciduous forest agro-ecological zone. Akatsi is located at latitude 6° 8'40.50"N, longitude 0°49'22.05"E and altitude 57m above sea level in the coastal savannah zone. Wenchi is located at latitude 7°45'17.82"N, longitude 2° 5'29.31"W and altitude 278 m above sea level in the forest-transitional zone of the Brong-Ahafo Region.

Fig. 16: Map showing the sites where the soil samples were taken

3.2 Materials and Instrumentation

The main materials for the construction of the tester include 3mm mild steel plate (2 pieces), 75mm $\times$75mm angle iron (2 pieces), 50mm shaft, 30mm shaft, ploughshare holder, pulleys of diameters 300mm, 100mm and 125mm (two pieces), 15 kW variable speed motor, B-type V-belts, 2 flange bearings, the cast steel ploughshare and 900mm metallic arm.

Other equipment used include a MEMMERT ventilated laboratory electric oven, a ADAM electronic balance, a tachometer, a set of spanners, a stop watch, a vernier calliper, empty cans and core samplers, a profile meter and a cone penetrometer with a semi-angle of 30° and cone base area of 2cm^2 (Eijkelkamp Agrisearch Equipment, Netherlands).

3.2.1 Description of the ploughshare

The cast steel ploughshare used was produced and described by Bobobee *et al* (2007) for animal- drawn implements. Its chemical composition is indicated in Table 1. The average nominal mass of the ploughshare is 2370 g. Its dimension is 350 mm wide, 100 mm high and 12 mm thick.

Table 1: Chemical composition of the ploughshare

Element	**C**	**Mn**	**Ni**	**Cr**	**Si**	**S**	**P**
%	0.4-0.5	0.6-0.7	0.2-0.3	0.1-0.2	1.6-1.6	0.12	0.05

Source: Bobobee *et al*, 2007

Fig. 17: Ploughshare used in the experiments

3.3. The Design of the Equipment

The objective for designing the equipment was to test the wear of tillage tools such as ploughshares in the laboratory. The distinguishing characteristic of the equipment is to allow the share to keep moving in the soil under controlled conditions. According to Al-Janobi and Eldin (1997), soil bins can be straight or circular depending on the type of study, space, energy requirement and financial constraints. Upon careful considerations, the soil bin was designed to be circular. The equipment operates according to the working principles given by Yu and Bhole (1990) and Bahyan (2006). The main component of the equipment are: circular soil bin, roller, scraper, share holder, a rotating arm and shaft, a support frame as well as the power transmission system. The design criteria included design for ease of operation and maintenance, safety and cost effectiveness. The choice of construction materials for the various parts of the equipment was based on availability, cost and efficiency.

3.3.1 Formulae used in the Design of the Equipment

The following equations (1 to 10) were used for the design of the equipment. The detail calculations are presented in Appendix 3.

Formulae for Design Calculations:

$$L_b = 2C + \frac{\pi}{2}(D + d) + \frac{(D - d)^2}{4C} \qquad 1$$

$$\beta = 180^\circ - 60^\circ \frac{(D-d)}{C} \qquad 2$$

$$T_2 = \frac{T_1 - mv^2}{C_1} + mv^2 \qquad 3$$

$$P = (T_1 - T_2)\ V \times n \qquad 4$$

$$T_e = \sqrt{(Km\,.\,M)^2 + (Kt\,.\,T)^2} \qquad 5$$

$$M_e = \left[\frac{1}{2}\left(K_m M + \sqrt{(Km\,.\,M)^2 + (Kt\,.\,T)^2}\right)\right] \qquad 6$$

$$\sqrt{M^2 + T^2} = \frac{\pi \tau {d_s}^3}{16} \qquad 7$$

$$P_s = \frac{2\pi NT}{60} \qquad 8$$

$$M = \frac{WL}{4} \qquad 9$$

$$D_c = \frac{F}{(4A)} \qquad 10$$

Where,

L_b= Length of V-belt

C = Centre distance between pulleys

D= diameter of bigger pulley

d = diameter of smaller pulley

T_e=Equivalent twisting moment (N-mm)

M_e = Bending moment of shaft (N-mm)

T= Torsional moment

τ =Yield stress of mild steel (N/mm^2) =215N/mm^2

d_s= diameter of shaft (mm)

M= Bending moment (N-mm)

W= Weight of Shaft (N)

L= Length of shaft (m)

P_s= Power transmitted by shaft (W)

N= rotational speed of the shaft (rpm)

K_m = Combined shock and fatigue factor for bending

K_t = Combined shock and fatigue factor for torsion

D_c = compressive stress on the frame (N/m^2)

A= cross-sectional area of each support leg (angle iron) (m^2)

β =Arc contact

T_1=Tension on tight side of the belt

T_2 =Tension on slack side

m = mass of belt/length

V =Belt speed

P =Power transmitted by the belt

n =number of belts

F= Total force on frame

(Khurmi and Gupta, 2003; Manuwa *et al*, 2011)

3.3.2 Force Prediction of the ploughshare in the soil

Some equations which have been developed were for simple blades passing through soil depending upon their depth/width (d/w) ratio are given as:

i. Wide tine (blades) for which $d/w<0.5$

ii. Narrow (chisel) tine for which $1<d/w<6$

iii. Very Narrow(knife) tines for which $d/w>6$

(Godwin and O'Dogherty, 2006)

The experiment was carried out using the cast steel ploughshare developed by Bobobee *et al,* (2007). The ploughshare was attached to its holder inside the soil bin in such a way that it was completely buried in the soil. It has a depth of 100mm and a width of 350mm. The aspect ratio (depth – width ratio) was 0.29. Therefore the wide tine force prediction model was chosen for predicting soil forces.

3.3.3 Wide tine force prediction equations

The equations for predicting the draught force in wide tines are given as follows:

$$H = \left(\gamma d^2 N_\gamma + C d N_c + q d N_q\right) w \qquad 11$$

$$N_{\gamma=\delta} = N_{\delta=0}\left[\frac{N_{\delta=\phi}}{N_{\delta=0}}\right]^{\delta/\phi} \qquad 12$$

Where

H= Draught Force, kN

C= Soil Cohesion, kNm^{-2}

γ= Bulk Density, kNm^{-3}

ϕ= Angle of soil-soil friction,°

w = Width of blade, m

d = Depth of tine from soil surface, m

q = Surcharge, kNm^{-2}

δ = Angle of soil-metal friction, °

α =Rake angle, °

N=Dimensionless number (suffixes: γ, gravitational; C, cohesive/adhesive; q, surcharge)

(Godwin and O'Dogherty, 2006)

Note: The N-factors could only be determined by the use of the charts found in Appendix 4.

3.4 Construction of the Equipment

The equipment was constructed at the workshop of Agricultural Engineering Department, Kwame Nkrumah University of Science and Technology in Kumasi, Ghana. Work on the construction began in August, 2010 and was completed in December, 2010. The general manufacturing processes used in the construction of the equipment involves marking, cutting, drilling, grinding, turning, milling, welding, rolling, fastening, bending and shaping. The abrasive wear tester was built in four stages. The first was the support frame to carry the soil bin, the second was the circular soil bin, the third was the arm sub-assembly which consists of the main shaft and the branches on the shaft and the extension legs that are connected to the branches, and the last was the power transmission system.

3.4.1 The Support Frame

The support frame was constructed by using angle iron of size 5x75x75mm. It was first marked into four parts of lengths 700mm. Another set of angle irons were cut into four parts each of length 1000mm. A full length of angle iron was cut into six pieces of length 900mm. Two 12 mm diameter holes (each) were drilled around the centre of four of the 1000mm angle irons. The four 1000 mm length were welded together to form a square brace. The four 700mm parts were also joined to each corner of the square brace to form the legs of the frame. Four sets of footings were joined under the legs to give them the needed stability. The six 900mm parts were joined to the sides and middle of the standing frame.

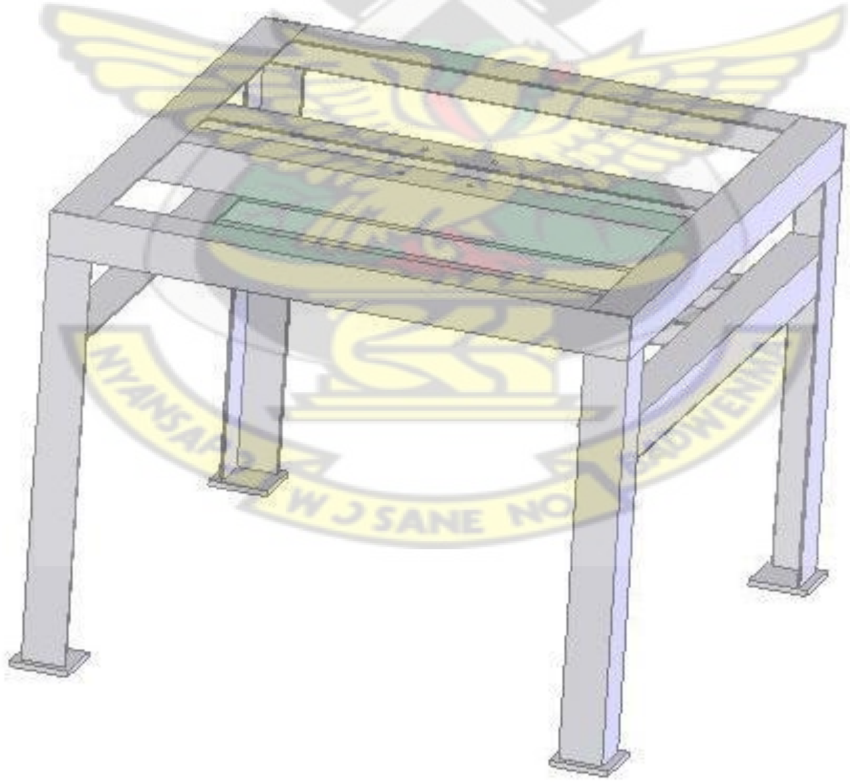

Fig.18: Support Frame

3.4.2 The Circular Soil Bin

A full mild steel plate was rolled using a rolling machine and the ends welded to form a cylinder of 1000mm diameter. Another part of the plate was cut using the cutting machine and a chisel to form the cylindrical base also of 1000mm diameter. A hole of diameter 50mm was cut at the centre of the cylindrical base. The cylindrical base was then welded unto the bottom part of the cylinder. A cylindrical pipe of diameter 100mm and height 500mm was placed at the centre of the base of the bigger cylinder and welded unto it. A 20mm angle iron was rolled and fixed unto the edge of the bigger cylinder by welding.

.

Fig. 19: Circular Soil Bin

3.4.3 The Arm Sub-assembly

This comprises the 50 mm and 25 mm diameter shafts, 900mm arm, roller, scraper, share holder and a ploughshare. The 50mm shaft was machined according to the dimensions given in the design. Three points on the metallic arm were marked and punched using a scriber and centre punch. One point was at the centre, the other was 225mm away from the centre and the third mark was placed at the opposite side with a distance of 250mm from the centre. Two holes of diameter 25mm were drilled at these points (leaving the centre point). A hub of inner diameter of 50mm and outer diameter of 60mm was placed and welded around the centre mark of the arm. Two shafts of diameter 25mm and lengths 300mm and 430mm respectively were cut using the power hacksaw machine. Threads of diameter 25mm were formed to a depth of 70mm on each shaft. Two holes of diameter 12mm were drilled 150mm apart on a metallic plate of 180mm length and 80mm thickness. This metallic plate (the share holder) was then welded unto 30mm diameter shaft of 300mm length.

A roller was fabricated using two (2) steel pipes of diameters 125mm and 25mm respectively, two (2) bushings of inner diameter of 20mm and a flat bar. It was fabricated according to the dimensions in the design. A scraper which consists of a flat bar and a plate was formed in such a way that the angle between the plate and the flat bar is 45˚. It was then joined by welding to the flat bar close to the side of the bigger cylinder (by welding). The shaft of diameter 25mm and length 300mm was welded unto the centre of the flat bar which forms the brace for the roller.

The main transmission shaft was fixed together with two flange bearings. The ploughshare was fixed unto the share holder by using two M12 bolts, nuts and flat washers. The shaft holding the ploughshare was fixed into the hole on the main metallic arm which is 225mm away from the centre using flat washers as well as two nuts. The roller sub-assembly was fixed unto the main metallic arm by inserting the threaded end of the shaft into the hole which is 250mm away from the centre of the arm. Flat washers as well as two nuts were then used to tighten them together using combination spanners. The other sub-assemblies forming the complete arm sub-assemblies were then fully assembled.

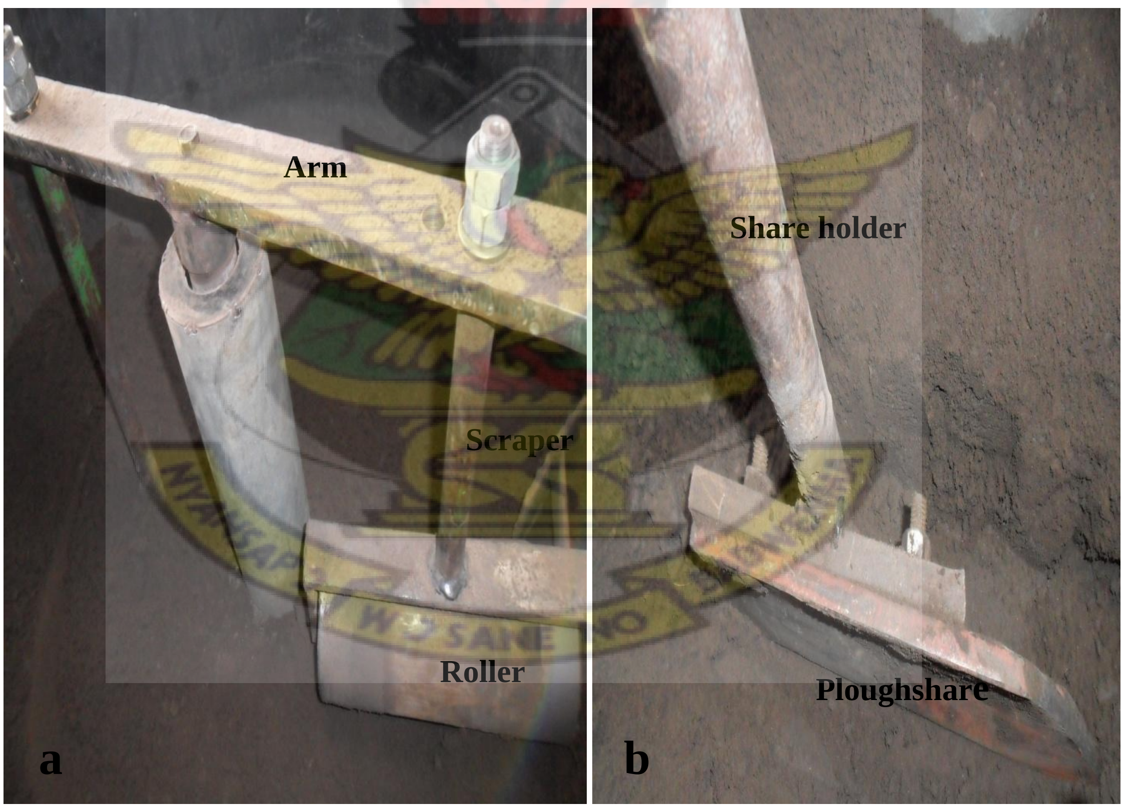

Fig. 20: (a) Roller and other arm sub-assemblies (b) Ploughshare positioned in the soil

3.4.4 Power Transmission System

This system comprises a 15kW three-phase variable speed electric motor, a bevel gear box, V-belts, aluminium pulleys of sizes 150mm, 100mm and 300mm. One 150mm diameter pulley was fixed unto the transmission of the motor and another one was fixed unto the input shaft of the bevel gear. A pulley of size 100mm was fixed unto the output shaft of the bevel gear. The other 300mm pulley was fixed unto the end of the main transmission shaft of the equipment below the soil bin. This was to ensure that the speed from the motor which was set at 120 rpm was reduced to one-third (40 rpm). Two V-belts each were used to join the pulleys joining the motor and the bevel gears and also that joining the pulleys from the output of the bevel gear and the main transmission shaft.

Figure 21: Power Transmission System

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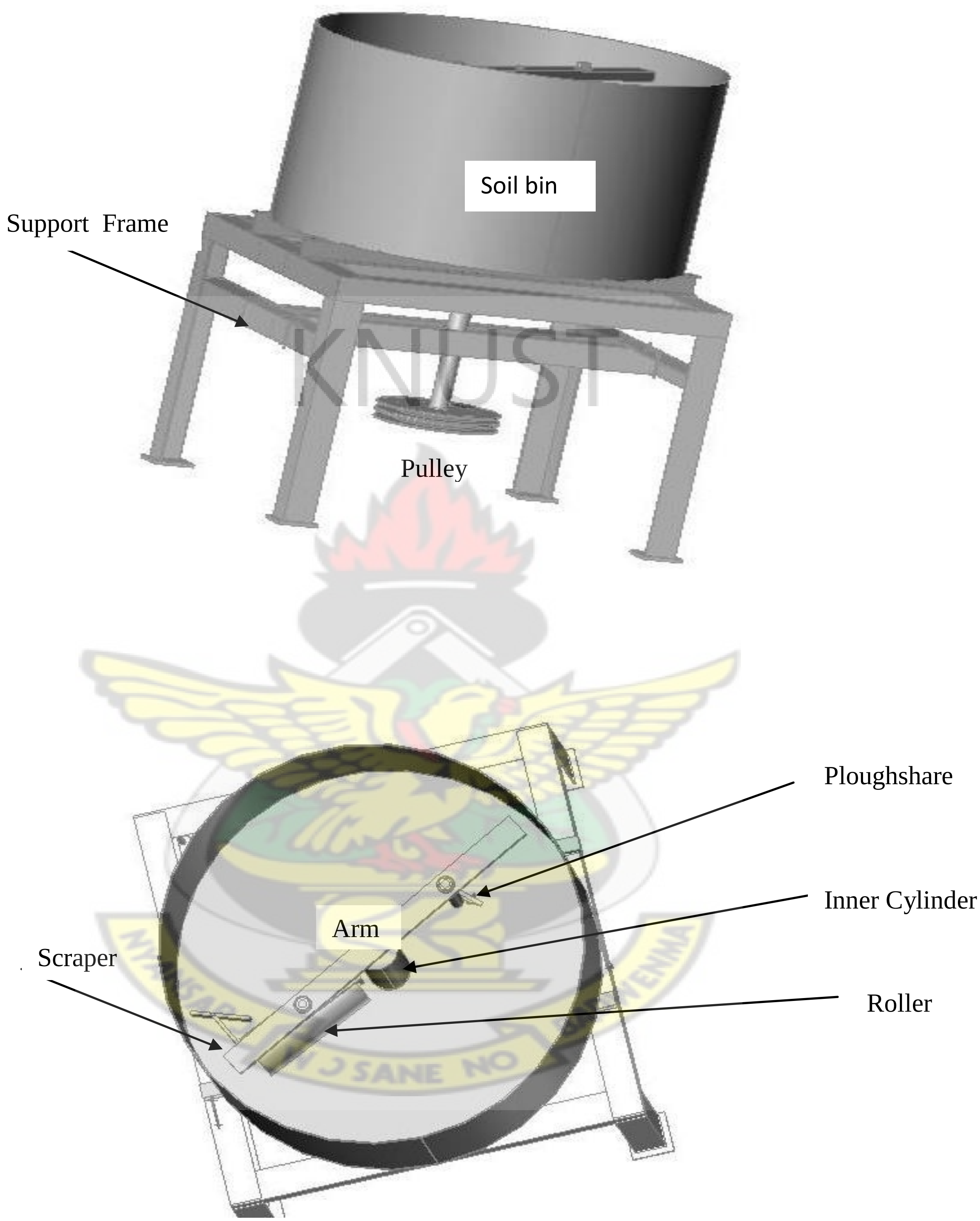


Fig. 22: Assembly 3-D drawing of the equipment

3.5 Experimental Procedure for Wear Measurement

The ploughshare was cleaned with water, dried and weighed to the nearest gram on a precision electronic balance with an accuracy of 0.01g to record its initial mass. The outline of the ploughshare was drawn on a paper and points **a, b, c, d, e and f** indicated as shown in Fig.23. The circular soil bin was filled with soil sample to a depth of 170mm. To prepare the loose soil into a desired state, the soil was compacted by passing the roller over the soil. The soil moisture content was raised by adding water directly at the interface (Yu and Bhole, 1990; Spoor, 1969). The clean, dry ploughshare was fixed unto its holder and set for the equipment to run. The soil moisture content was measured before each experimental run by taking soil samples from the bin at the ploughshare's working area. The samples were then weighed , dried in an oven at 105°C for 24 hours and weighed again (ASTM, 1991). The ploughshare was washed with water, cleaned and weighed after every one (1) hour to determine the weight loss due to soil abrasion. The share was then clamped unto its holder and the process repeated up to five hours a day. The soil in the bin was covered with black polythene at the end of each day to reduce evaporation. Each experiment was repeated three (3) times. Moisture content, soil pH and penetration resistances were measured at the start of each run. On completing each experiment, the length differences (dimensional losses) were measured using a vernier calliper and a profile meter at the six points **a, b, c, d, e,** and **f** of the ploughshare.

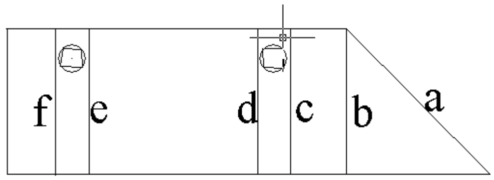


Fig. 23: Dimensional points on the ploughshare

3.5.1 Experimental Design: The experimental design used was the completely randomised design with six treatments of soils from Ho, Akatsi, Wenchi, Mampong, Akuse and KNUST. Each test was repeated three times.

Table 2: Textural/Taxonomy classification of the soil from the sites

Site	Depth (cm)	%sand	%silt	%clay	Textural class	FAO Classification
Ho	0 - 20	72.81	9.38	17.81	Sandy loam	Acrisol
	20 - 40	70.45	12.85	16.70	Sandy loam	
Akatsi	0 - 20	83.02	14.98	2.00	Loamy sand	Cambisol
	20 - 40	81.70	14.30	4.00	Loamy sand	
Mampong	0 - 20	67.33	6.95	17.81	Sandy clay loam	Lixisol
	20 - 40	51.66	26.34	22.00	Sandy clay loam	
Wenchi	0 - 20	66.26	6.36	27.38	Sandy clay loam	Lixisol
	20 - 40	60.40	31.60	8.00	Sandy clay loam	
KNUST	0 - 20	68.92	21.06	10.02	Sandy loam	Acrisol
	20 - 40	57.98	19.98	22.04	Sandy clay loam	
Akuse	0 - 20	60.74	2.11	37.16	Sandy clay	Vertisol
	20 - 40	64.70	11.80	23.50	Sandy clay loam	

The test conditions are given below:

Speed of rotation of transmission shaft: 40 rpm (3.3 km/h)

Soils: Six soils from different sites (Ho, Akatsi, Wenchi, Mampong, Akuse and KNUST))

Ploughshare size: 350 x 100 x 12 mm

Test time: 1 hour interval up to five (5) hours each day.

3.5.2 Procedure for pH measurement

A 10g air-dried soil was put into a 100ml beaker and 25ml of distilled water added. The suspension was stirred vigorously for the next 20 minutes and allowed to stand for about 30 minutes by which time the clay particles have settled from the suspension. The pH meter was calibrated. An electrode of the pH metre was inserted into the partly settled suspension. The pH value was then read and recorded.

3.5.3 Textural Classification: Composite soil samples were taken from 0 to 20 cm and 20 to 40 cm soil layers and analysed for particle size distribution and texture using the USDA textural triangle. Soils were air-dried and passed through a 2-mm sieve before analysis. Soil particle size distribution was measured by the hydrometer method (Gee and Bauder, 1986).

3.6 Data Analysis

The data recorded in the experiment were subjected to analysis of variance (ANOVA) using MINITAB statistical software Release 15 (Minitab Statistical Package, 2007). Least significant differences (LSD) were calculated from standard errors of the difference of the means. Statistical significance was set at $p<0.05$. All the graphs were plotted using Microsoft Excel (2007). Some of the graphs were bar charts with error bars while others were line graphs.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Introduction

The objective of the project was to develop and evaluate an abrasive wear test equipment. In this chapter, the results of the project are presented and discussed. The chapter also presents pictures and schematic drawing of the set-up. Finally the chapter ends by presenting the result of the evaluation. The evaluation was based on the comparison of wear and the influence of moisture content and pH on wear in the various soils. The results of the penetration resistance recorded in the experiments have also been discussed.

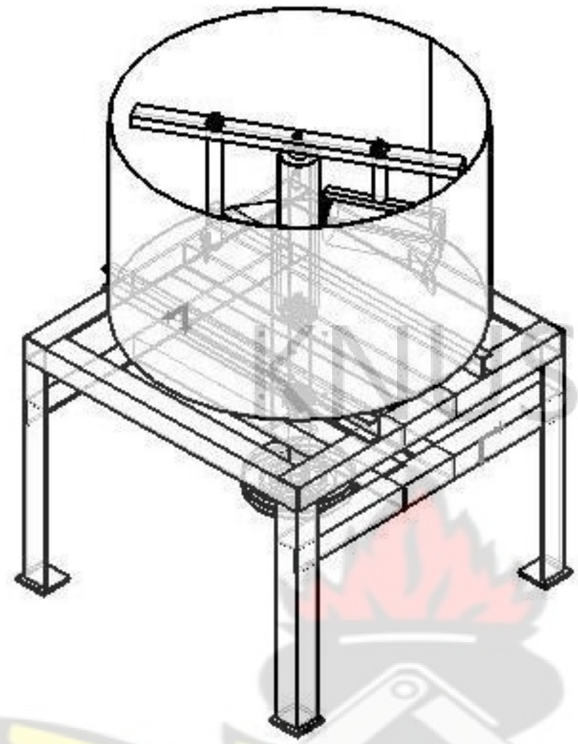
4.2 Design and Construction of the Abrasive wear test equipment

The equipment was designed and constructed for abrasive wear tests in the laboratory. The design criteria of the equipment and the processes used in the construction have been described in Section 3.3. Table 3 summarises the results of the mechanical design calculations. The calculations were done using the formulae in Section 3.3.1. From the design calculation, the shaft diameter was 43.9 mm but 50 mm was used to ensure safety. All the detailed calculation are found in Appendix 3. All the materials used for the construction were purchased from the local market in Kumasi.

Table 3: Results of Mechanical Design Calculations

Design property	**Assumed Parameters**	**Designed Parameters**
Length of belt	C=615, d_1=300, d_2= 100	L_b = 1874 mm
Diameter of shaft	T= 3581 x 10^3 N-mm M= 58920 N-mm T_e = 540.372 x 10^3 N-mm M_e = 228.612 x 10^3 N-mm K_m = 1.5 , K_t = 1.0	d = 43.9 mm
Roller Pressure	W = 9.2 kg , C=0.393 m, A = 0.009 m^2	P= 10 kPa
Compressive stress on support frame	F = 7486.6N ,A = 0.005625 m^2	D_c = 332.738 kPa
Power of Electric Motor	T_1=825N, T_2=447N, V=7.54m/s	1440 rpm, 5.7kW
Centre Distance of pulleys	d =100mm, D=300mm	C= 615mm
Tension in Belts	β=173.6˚ , V=7.54ms^{-1}, m=0.27	T_1 =825 N, T_2 = 447N
Belt speed	d= 100mm, D=300mm, N= 1440 rpm	V= 7.54 ms^{-1}
Arc of contact	D=300mm, d=100mm, C=615	β= 173.6˚
Speed ratio	D=300mm, d=100mm	0.33
Soil volume used	h= 170 mm, r_o= 500mm	V= 13.352 x 10^6 mm^3

(a)



(b)

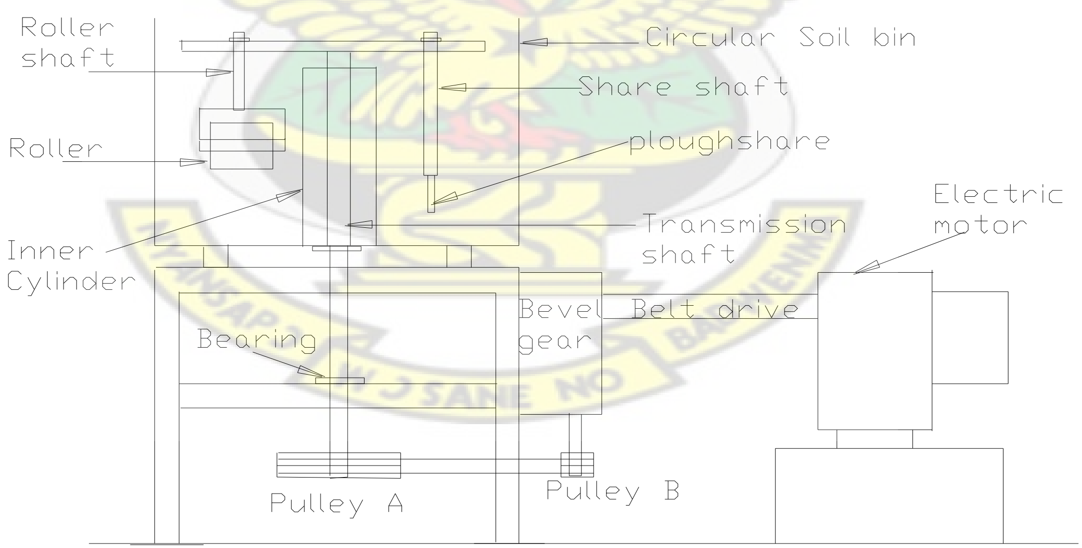


Fig. 24: (a) Isometric view of the equipment (b) Schematic diagram of the set-up

Fig. 25: (a) A view of the set-up (b) A view of the inside components of the equipment

4.3 Comparison of ploughshare wear in various soils

Fig. 26 shows the weight loss of the ploughshare in soils from Ho, Akatsi, Mampong, Wenchi, Akuse and KNUST. Analysis of variance showed significant difference ($p<0.05$) in the weight loss. The average weight loss of the ploughshare in the Ho soil was 3.6g , the Akatsi soil was 4.11g, the Mampong soil was 2.90g, the Wenchi soil was 2.88g , Akuse was 1.97g and the KNUST soil was 1.36g. This shows that the Akatsi soil had the greatest wear followed by Ho, Mampong, Wenchi, Akuse with the KNUST soil recording the least. From the texural analysis the depths of 0-20cm and 20-40cm, the Akatsi soil had the greatest sand content of 81.70,83.02% followed by Ho (70.45, 72.81%), Mampong(61.66 , 67.33%), Wenchi(60.40, 66.26%), Akuse (64.70,60.74%) and KNUST(57.98, 68.92%) respectively. Comparing the wear to the percentage of sand in the soil, the Akatsi soil recorded the highest average value of wear as a result of its highest percentage sand content followed by Ho soil with the KNUST soil recording the least wear. Although the KNUST soil had a comparatively equal sand content to the Wenchi, Mampong and Akuse soils, it recorded the least wear. This may be that more of the soil in the 20-40 cm horizon which had a sand percentage of 57.98% was used in the experiment. The general finding of the study shows that wear increases with increasing sand content which is in agreement with the reports of other researchers (Bobobee *et al* (2007); Natsis *et a*l (1999);Ferguson *et al* (1998); Yu and Bhole (1990)). According to Owsiak (1999), wear in sandy soil is 40-100% more than wear in clay. Again according to Scheffler and Allen (1988), wear was found to be twenty times higher in stony soils than in sandy soil and seven times greater than in clay soil.

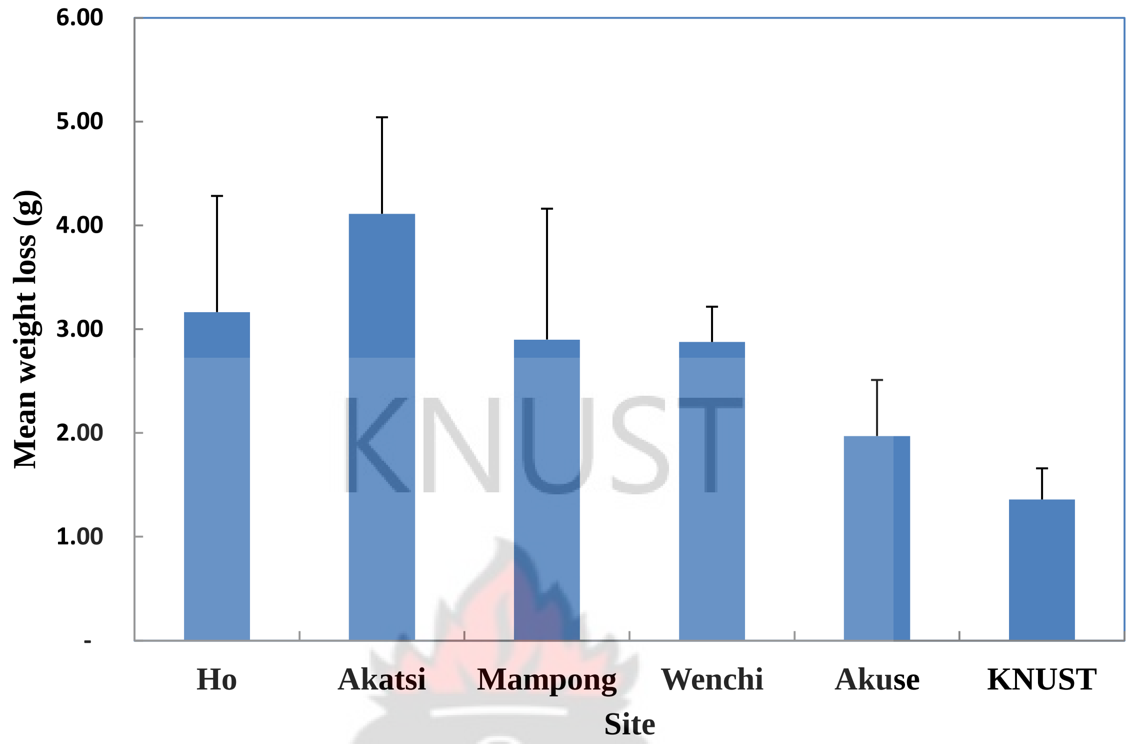


Figure 26: Mean weight loss of ploughshare in soils from the six sites

Fig. 27 shows the dimensional wear at the six different positions on the ploughshare marked as *a*, *b*,*c*,*d*,*e*,*f*. The points *a, b, c, d, e* and *f* could be named as shin, leading face, front, middle, back and tail respectively. The point '*a*', which is the shin on the share experienced the greatest wear in all the six soils. At this point, the Akatsi soil recorded the greatest value followed by Ho, Mampong,Wenchi, Akuse and KNUST soils. This is in direct agreement with weight losses recorded in Fig. 26. Dimensional wear in the Akatsi soil tend to be higher at most points except at points '*e* 'and '*f* '. The Ho soil followed after Akatsi soil at points '*a'* and '*b'* but dropped at points '*c'* and '*d'*. It however recorded the highest values at points '*e'* and '*f*'. It was also found that the ploughshare wore more at the bottom than any part. This could be as a result of the compaction of the soil in the circular soil bin which tends to increase with depth. From Fig. 31, the general penetration resistance increases with depth and this shows that there is more compaction at the bottom than at the top layer of soil in the soil bin. The findings of this study show that weight loss matches strongly with dimensional loss of the cast-steel ploughshare in all the soils. The result however disagrees with the findings of Graff *et al* (2007) who reported that mass change does not lead to the same conclusions as the length change.

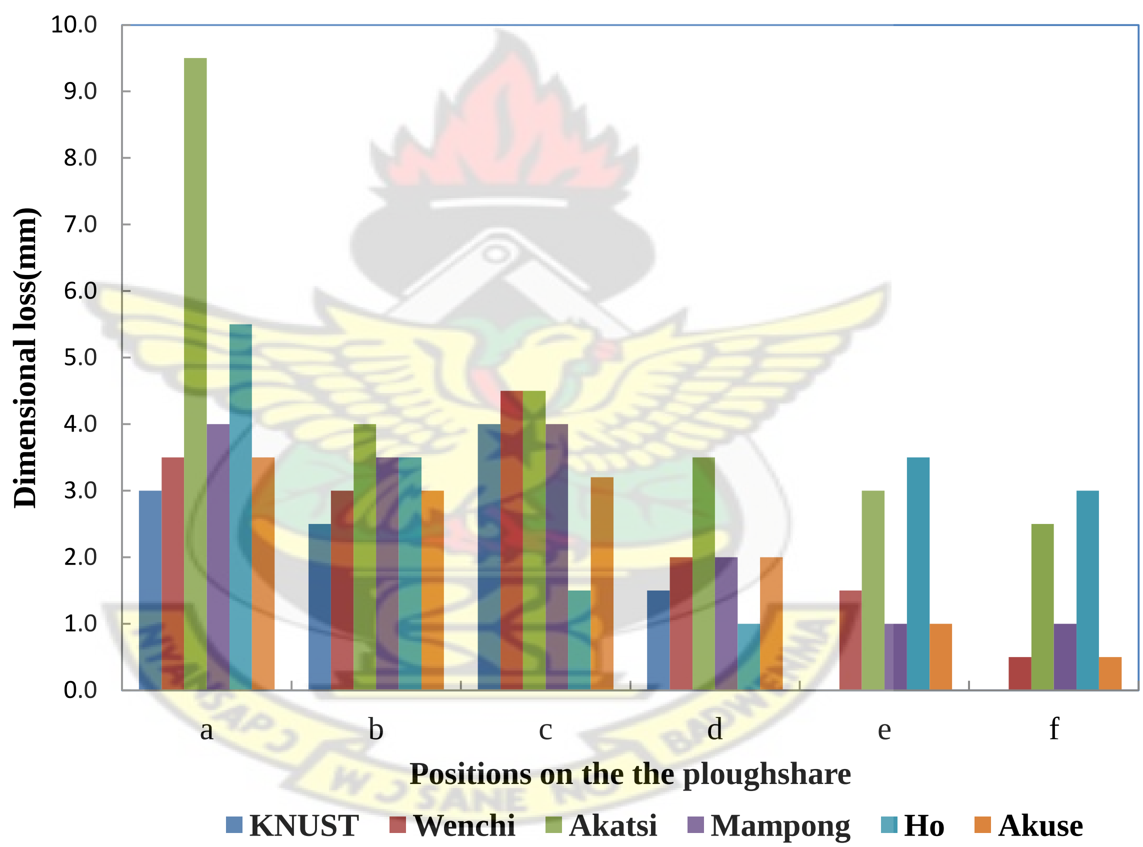


Figure 27: Dimensional losses at six points on the ploughshare

4.3.1 Relationship between duration of use and wear

Fig. 28 shows variation of cumulative wear of the ploughshare with respect to increasing duration of use for all the soils. The wear of the Akatsi and Mampong soil was the highest while Akuse soil recorded the least wear at the initial hour. However, the cumulative wear of the Akatsi soil increases from the first hour to the fourth hour before it falls slightly at the fifth hour. At this hour, it coincides with the cumulative wear of the Mampong soil. The Akatsi soil then increases consistently while that of the Mampong soil tend to be gentle. Even though the initial wear of the Ho soil is less than that of the Mampong soil, it tends to eventually have higher cumulative wear than the Mampong soil. In general, it is observed that the KNUST soil has the least cumulative wear. The cumulative wear of the Akatsi soil is the highest followed by that of Ho, Mampong, Wenchi, Akuse and KNUST.

The trend generally reveals that cumulative wear increases with increasing time of operation. This is in agreement with the results of Baryeh (2001) and Bhutta *et al* (1998). It also confirms that with time, the cumulative wear in the Akatsi soil is higher than all the other soils. Again KNUST recorded the least cumulative wear for 15 hours of operation at a constant speed of 3.3 km/h. It was observed that after five hours of operation, the cumulative wear in the Mampong soil rose from 12.67g sharply to 21.77g which was more than that of the Akatsi soil which had 21.12g after which it increased gently to 22.77.The Mampong trend fell to a final cumulative value of 45.73g which was lower than that of Ho soil which had a value of 47.46g. The reason behind this observation was as a result of differences in moisture contents of the soils after the fifth hour. At that stage, the moisture content recorded in the Mampong soil was higher than those of the Ho and Akatsi soils. Wear was found to be decreasing with increasing moisture content in the Mampong soil while the reverse was happening in the Ho and Akatsi soils.

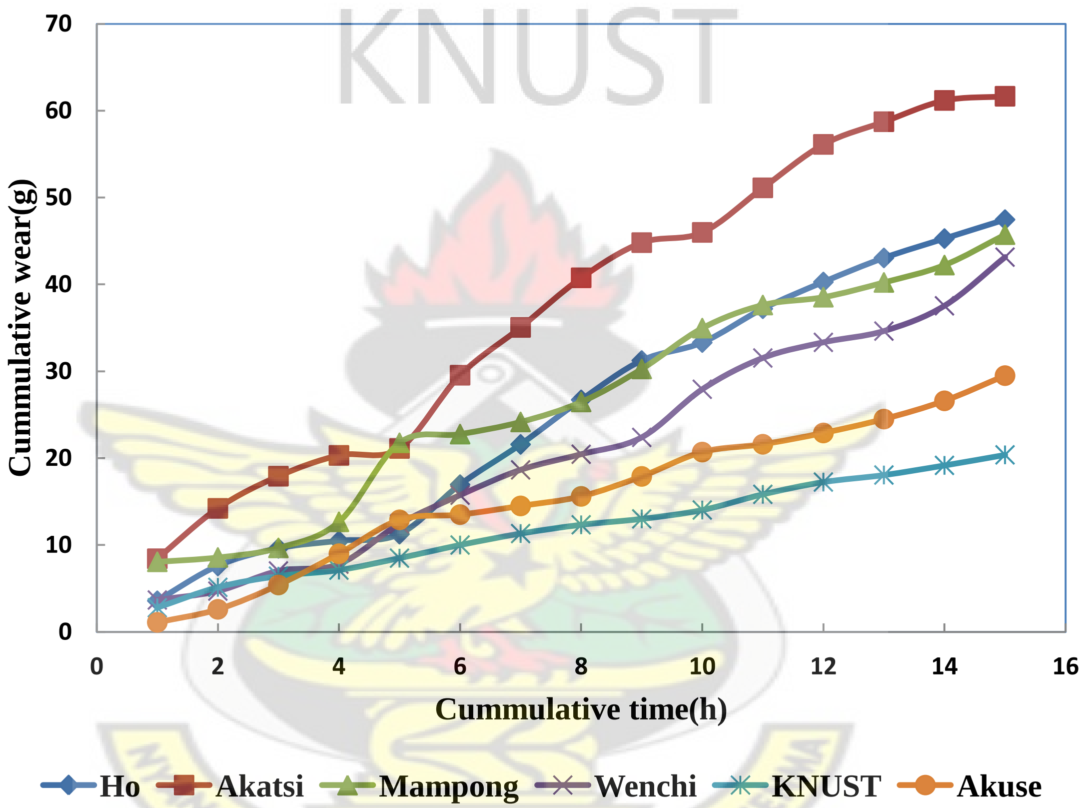


Figure 28: Variation of wear with duration of use

4.4. Influence of moisture content on Wear

Figure 29 shows the influence of moisture content on the wear rate of the ploughshare. Table 4 also shows the equation that could be used to determine the wear rate of the ploughshare, their corresponding coefficient of determination (R^2), percentage sand contents and texture of the soils from the six sites. For the Akatsi and Ho soils, the wear rate increased with an increase in moisture content. The relationship is polynomial for Akatsi but linear for the Ho soil. There is a high coefficient of determination (R^2) of 0.991 and 0.973 for Ho and Akatsi soils respectively. The linear trend of the Ho soil in fig. 29 tends to agree with the findings of Yu and Bhole, (1990) who found that the wear of tillage tools increase linearly with soil moisture content in sandy loam soils. Baryeh (2001) also found out that the wear of a Ghanaian hoe in loamy soil increases linearly with an increase in moisture content. In general, as the moisture content increases, the soil particles (mostly sand) are free to move which cause more abrasion between the ploughshare and the soil particles. This is in agreement with the findings of Natsis *et al*, (1999) who found that the wear of a mouldboard plough increased with increasing moisture content in sandy soils.

Soils from Akuse, Mampong and Wenchi showed a general trend of decrease in wear rate with increasing moisture content. However the trend for Akuse was linear while that of the Mampong and Wenchi soils were polynomial. Also the wear rate of the Akuse soil gave a very high coefficient of determination (R^2) of 0.992. The wear rate of the Wenchi and Mampong soils initially decreased with increasing moisture content from 8.8% for Wenchi and 11.54% for Mampong up to 13% for Wenchi and 15.5% for Mampong after which the wear increases with increasing moisture content. From the USDA textural class classification they have the same texture (sandy clay loam) and have a high percentage of clay content. In this case, at a higher moisture contents, there is strong bonding between the clay particles causing them to be sticky. This causes reduction in the wear of the ploughshare. However the trend changes after 13% and 15.5% moisture contents for Wenchi and Mampong respectively. This may be due to the fact that after this point, moisture content in the soil will reduce the ability of the soil to stick unto the blade and may increase the abrasion between the soil particles and the contact surface of the ploughshare. The change in trend occurs earlier in the Wenchi soil more than the Mampong soil. This may be due to relatively a lower clay content in the latter than the former. The trend agrees with the reports of Ferguson *et al*, (1998) and Natsis *et al*, (1999) who reported that wear decreases with increasing moisture content for clay and loam respectively. The texture of soil from KNUST was a mixture of sandy loam (0-20 cm depth) and sandy clay loam (20-40 cm depth). As a result of this the trend showed polynomial relationship with a gentle decrease in wear rate from 7.85% to 10% after which the wear rate increased with increasing moisture content. The Akuse soil also showed a linear trend of decreasing wear rate with increasing moisture content. The general findings of this study indicate similar wear rate trend for soils from Wenchi, Mampong, KNUST and Akuse.

The main difference between this study and other studies (Baryeh, 2001; Miller, 1984; Ferguson *et al*, 1998) is the differences in the moisture content range. While this study recorded moisture content up to 18%, others recorded it up to 30%. However, in this study moisture content was kept low to simulate real field conditions for ploughing. On the field, when the moisture content is too high it makes ploughing difficult. Baryeh (2001) reported that it is advisable to till the land at low moisture content at the beginning of the rains when the moisture content is usually between 5% and 15%.

Ahmadi and Mollazade (2009) also reported that tillage can be carried out in soils with moisture content up to 18%.

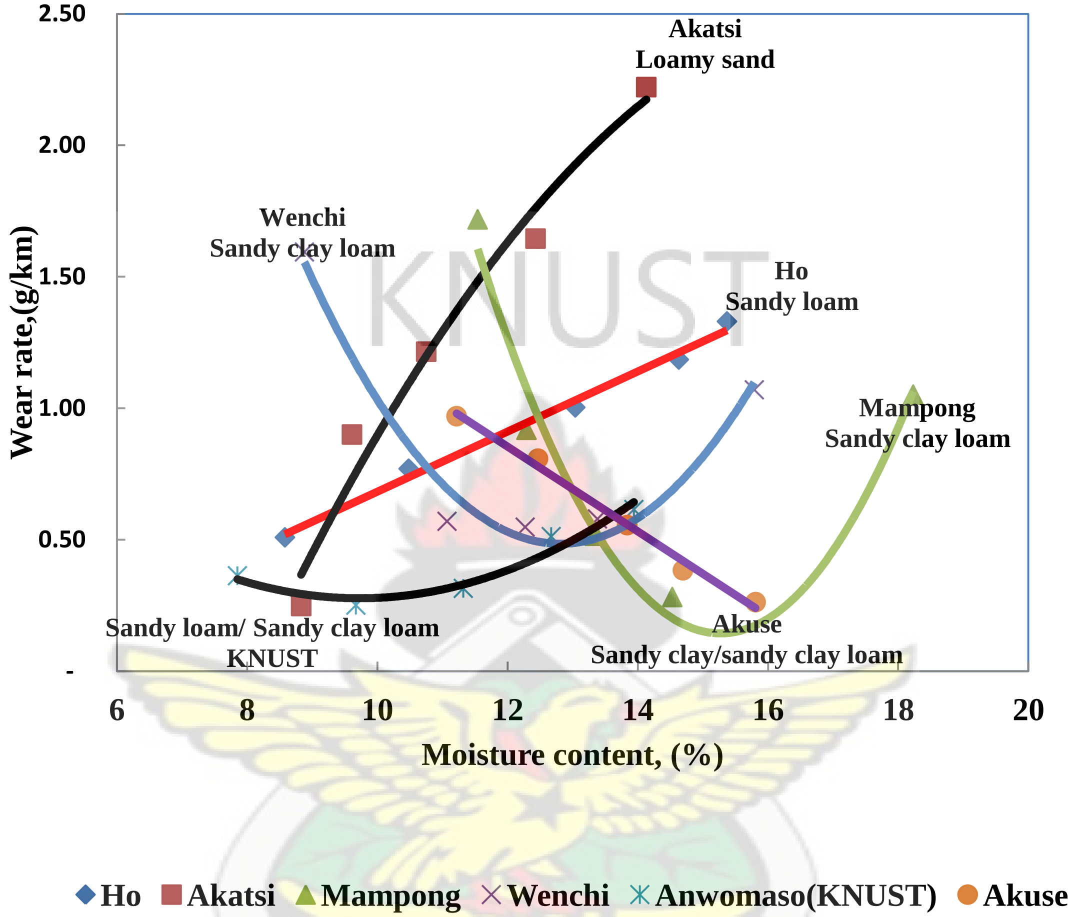


Figure 29: Relationship between wear rate and moisture content

Table 4: Equations, coefficients of determination and other soil descriptions

Site	Equation	(R^2)	Highest sand %	Texture
Ho	$y = 0.1144x – 0.4615$	0.991	72.81	Sandy loam
Akatsi	$y = -0.0273x^2 + 0.9672x – 6.0462$	0.973	83.02	Loamy sand
Mampong	$y = 0.1051x^2 - 3.2092x + 24.626$	0.963	67.33	Sandy clay loam
Wenchi	$y = 0.0692x^2 – 1.774x + 11.85$	0.974	66.26	Sandy clay loam
KNUST	$y = 0.0205x^2 – 0.399x + 2.219$	0.944	68.9	Sandy loam/ Sandy clay loam
Akuse	$y = -0.16x + 2.7865$	0.992	64.70	Sandy clay/ Sandy clay loam

4.5 Influence of soil pH on wear

A typical result of the variation of soil pH with wear rate is shown in Figure 30. The highest pH is recorded in the Akuse soil (5.64) followed by soils from Ho (5.40), Wench(5.19), Akatsi (5.18), KNUST (4.09) and Mampong (3.76). The Mampong soil tends to be the most acidic. Even though analysis of variance showed significant differences ($p<0.05$) in the pH values in the various soils, it was observed that this does not have significant effect on the wear rate of the ploughshare. Generally it is accepted that pH may influence the corrosion rate of metals. Wear is a mechanical material degradation process occurring on rubbing or impacting surfaces, while corrosion involves chemical or electrochemical reactions of the material. Watson *et al*, (1995) found that corrosion may accelerate wear and wear may accelerate corrosion. According to DOE (1993), in the range of pH 4 to pH 10, the corrosion rate of iron is relatively independent of the pH of the solution. Except for Mampong soil, the pH of all the other five soils fell within this range. Also according to Batchelor and Stachowiak (1988), a significant synergism between corrosion and abrasion only occurs when the static corrosion rate is more than half the time-based abrasion rate. This shows that the pH of the soils did not influence the corrosion rate which eventually may influence the abrasive wear of the ploughshare. The relationships observed in Figure 30 indicate that the pH has no influence on the abrasive wear of the ploughshare.

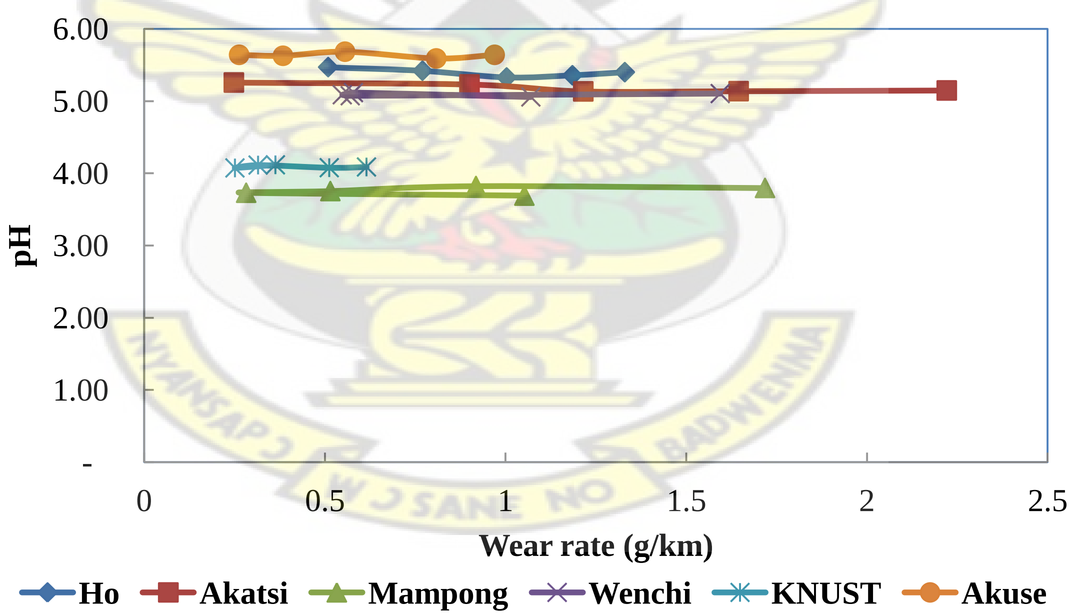


Figure 30: Variation of soil pH with wear rate

4.6 Soil penetration resistance in the soil bin

From fig. 31, the penetration resistance increases with increasing depth. This observation means that the deeper the ploughshare enters the soil, the more soil resistance it will experience which influences its wear rate. The penetration resistance of the Wenchi and KNUST recorded the highest values of approximately 2.4MPa. This may be as a result of the high clay content in these soils which tends to increase compaction in the soil bin. Comparing the result of the study to that obtained using a soil bin which had no roller to compact the soil, it was deduced that wear rate in compacted soil was 29 to 57% greater than that in loose soil. According to Owsiak (1997), high penetration resistances are expected in compacted soil indicating increased unit pressure and hence increased abrasive forces which cause the wear to be 31% greater than those in loose soil. This agrees with the findings of this study. It also shows that the Mampong soil with the highest moisture content recorded the least range of penetration resistance. However, the KNUST soil with the lowest moisture content also gave the highest penetration resistance. This confirms that soil moisture content is the most important factor influencing soil compaction processes (Hamza and Anderson, 2005). According to Lipiec et al (2002), at all levels of soil compaction, the penetration resistance increases with decreasing soil moisture potential. This means increasing soil moisture content causes a reduction in the load support capacity of the soil (Kondo and Dias Junior, 1999) thus decreasing the permissible ground pressure (Medvedev and Cybulko, 1995). Even though there is a high correlation between moisture content and penetration resistance, Bobobee *et al* (2007) reported that this has very little influence on the wear rate of ploughshares. This agrees with the findings of this study.

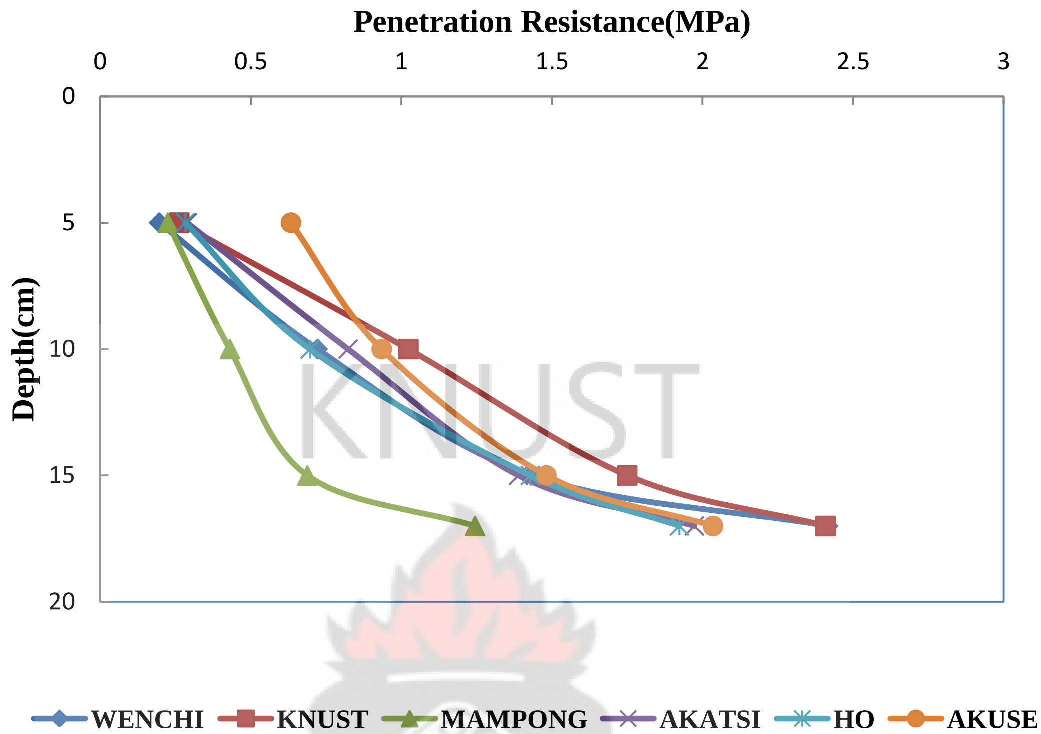


Figure 31: Penetration Resistance at different depths

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. A circular abrasive wear equipment has been developed and it is able to perform its function. It was constructed using locally available materials. The design is such that it can be used to test the wear of a particular tillage tool using different soils. This is a useful laboratory equipment for carrying out basic and applied research in the Universities, Polytechnic, research institutes and industries. The results of such tests could be used to assess the wear rate of soil engaging parts of agricultural machines.

2. From the evaluation, Akatsi soil with the highest sand content had the greatest wear rate followed by Ho, Mampong, Wenchi and Akuse. KNUST soil recorded the least wear. Thus the higher the sand content, the higher the wear rate of the cast-steel ploughshare. The weight loss (g) matched with the dimensional loss (mm) of the cast-steel ploughshare and the sand content of the soils.

3. Moisture content influenced the wear rate of ploughshare in the soils. For soils from Ho and Akatsi which had texture of sandy loam and loamy sand soils, respectively, the wear of the ploughshare increased as the soil moisture content increased. On the contrary, the Wenchi, Mampong, KNUST and Akuse soil which were mostly sandy clay loam in texture, the wear decreased with increasing moisture content up to a point before the trend reversed. The influence

of moisture content on the wear rate of the ploughshare was found to be dependent on the soil type.

4. The pH of the soil recorded in the experiment for the six soils was acidic in nature. However it did not influence the abrasive wear of the ploughshare.

5.2 Recommendations

1. This study developed an abrasive wear test equipment which is able to operate one ploughshare (other tillage tools) in a particular soil at a time. This means that only one tool could be used at a time. The limitation here is that one cannot compare the wear of different tools in a particular soil. It is therefore recommended that further work should be carried out to develop abrasive wear test equipment which could operate two different tillage tools simultaneously.

2. The soils used in this study were mainly. Sandy loam, sandy clay loam, loamy sand and sandy clay. It is recommended that further work should be carried out using soils of different texture.

3. The present study was conducted at a constant speed of 40 revolutions per minute. This translated into 3.3 km/h linear speed. However since ploughing could be done at different speeds. Tractors could plough within the range of 4 to 6 km/h. Therefore, it is recommended that further work should be considered using the equipment at different speeds of operation such as 50, 60 and 70 rpm

4. The results of the study indicate that all the soils were acidic in nature. It is suggested that further work should be carried out to find the effect of corrosion on abrasive wear.

5. This study was conducted using a ploughshare with the same hardness. It is therefore suggested that techniques for improving the hardness (such as hot stamping and hardfacing) should be applied to it and experiments conducted to

investigate how they wear. This would help to find the best method for improving the wear resistance of the share.

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APPENDICES

Appendix 1: Data Analysis

Weight Loss (g)

One-way ANOVA: Ho, Akatsi, Mampong, Wenchi, KNUST, Akuse

```
Source  DF      SS     MS     F      P
Factor   5  13.850  2.770  3.96  0.024
Error   12   8.387  0.699
Total   17  22.237

S = 0.8360   R-Sq = 62.28%   R-Sq(adj) = 46.57%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev  --------+---------+---------+---------+-
Ho       3  3.1633  1.1179              (------*------)
Akatsi   3  4.1067  0.9252                    (------*------)
Mampong  3  2.9600  1.2608             (------*------)
Wenchi   3  2.8767  0.3362            (------*------)
KNUST    3  1.3600  0.3051  (------*------)
Akuse    3  1.9667  0.5405      (------*------)
                            --------+---------+---------+---------+-
                                  1.5       3.0       4.5       6.0

Pooled StDev = 0.8360


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons

Individual confidence level = 99.43%


Ho subtracted from:

           Lower   Center   Upper  -------+---------+---------+---------+--
Akatsi   -1.3494   0.9433  3.2361                (-------*-------)
Mampong  -2.4961  -0.2033  2.0894            (-------*-------)
Wenchi   -2.5794  -0.2867  2.0061           (--------*-------)
KNUST    -4.0961  -1.8033  0.4894      (-------*--------)
Akuse    -3.4894  -1.1967  1.0961        (-------*--------)
                                   -------+---------+---------+---------+--
                                       -3.0       0.0       3.0       6.0


Akatsi subtracted from:

           Lower   Center    Upper  -------+---------+---------+---------+--
Mampong  -3.4394  -1.1467   1.1461       (------*-------)
Wenchi   -3.5228  -1.2300   1.0628      (--------*-------)
KNUST    -5.0394  -2.7467  -0.4539  (-------*------)
Akuse    -4.4328  -2.1400   0.1528    (-------*--------)
                                    -------+---------+---------+---------+--
                                        -3.0       0.0       3.0       6.0


Mampong subtracted from:
```

```
          Lower   Center   Upper  -------+---------+---------+---------+--
Wenchi  -2.3761  -0.0833  2.2094           (-------*------)
KNUST   -3.8928  -1.6000  0.6928      (-------*------)
Akuse   -3.2861  -0.9933  1.2994        (-------*------)
                                  -------+---------+---------+---------+--
                                      -3.0       0.0       3.0       6.0


Wenchi subtracted from:

         Lower   Center   Upper  -------+---------+---------+---------+--
KNUST  -3.8094  -1.5167  0.7761      (-------*-------)
Akuse  -3.2028  -0.9100  1.3828        (-------*-------)
                                 -------+---------+---------+---------+--
                                     -3.0       0.0       3.0       6.0


KNUST subtracted from:

         Lower  Center   Upper  -------+---------+---------+---------+--
Akuse  -1.6861  0.6067  2.8994            (-------*-------)
                                -------+---------+---------+---------+--

                                    -3.0       0.0       3.0       6.0
```

Since $P<0.05$, then the wear of the ploughshare is significantly different from soil to soil

LSD = $SE_{\text{difference of any two means replicates}} \times t_{\text{error df@5\%}}$

$$LSD = \sqrt{\frac{2\ x\ Error_{MS}}{r}}\ x\ t_{\text{error df@5\%}}$$

$$= \sqrt{\frac{2\ x 0.699}{3}}\ x\ 2.179$$

=1.4875

Treatment	Ho	Akatsi	Mampong	Wenchi	Akuse	KNUST
Mean	3.16	4.11	2.90	2.88	1.97	4.09

Akatsi > Ho > Mampong > Wenchi > Akuse >KNUST

Moisture Content

One-way ANOVA: Ho, Akatsi, Mampong, Wenchi, KNUST, Akuse

```
Source  DF     SS    MS     F      P
Factor   5  20.07  4.01  3.87  0.026
Error   12  12.45  1.04
Total   17  32.52

S = 1.019   R-Sq = 61.70%   R-Sq(adj) = 45.75%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level    N    Mean  StDev  -----+---------+---------+---------+----
Ho       3  12.427  0.552           (--------*--------)
Akatsi   3  11.150  0.404   (--------*---------)
Mampong  3  13.920  1.785                     (---------*-------)
Wenchi   3  12.260  1.550          (---------*-------)
KNUST    3  11.090  0.404  (---------*-------)
Akuse    3  13.440  0.087                  (---------*-------)
                           -----+---------+---------+---------+----
                             10.5      12.0      13.5      15.0

Pooled StDev = 1.019


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons

Individual confidence level = 99.43%


Ho subtracted from:

          Lower  Center  Upper  ---------+---------+---------+---------+
Akatsi   -4.071  -1.277  1.517       (---------*--------)
Mampong  -1.301   1.493  4.287                 (---------*---------)
Wenchi   -2.961  -0.167  2.627             (---------*---------)
KNUST    -4.131  -1.337  1.457       (---------*--------)
Akuse    -1.781   1.013  3.807                 (---------*---------)
                                ---------+---------+---------+---------+
                                      -3.0       0.0       3.0       6.0


Akatsi subtracted from:

          Lower  Center  Upper  ---------+---------+---------+---------+
Mampong  -0.024   2.770  5.564                     (---------*---------)
Wenchi   -1.684   1.110  3.904               (---------*---------)
KNUST    -2.854  -0.060  2.734           (---------*---------)
Akuse    -0.504   2.290  5.084                   (---------*---------)
                                ---------+---------+---------+---------+
                                      -3.0       0.0       3.0       6.0


Mampong subtracted from:

         Lower  Center   Upper  ---------+---------+---------+---------+
Wenchi  -4.454  -1.660   1.134      (---------*---------)
KNUST   -5.624  -2.830  -0.036  (---------*---------)
Akuse   -3.274  -0.480   2.314          (---------*---------)
```

```
                                  ---------+---------+---------+---------+
                                        -3.0       0.0       3.0       6.0


Wenchi subtracted from:

        Lower  Center  Upper  ---------+---------+---------+---------+
KNUST  -3.964  -1.170  1.624        (---------*---------)
Akuse  -1.614   1.180  3.974                (---------*---------)
                              ---------+---------+---------+---------+
                                    -3.0       0.0       3.0       6.0


KNUST subtracted from:

        Lower  Center  Upper  ---------+---------+---------+---------+
Akuse  -0.444   2.350  5.144                    (---------*---------)
                              ---------+---------+---------+---------+
                                    -3.0       0.0       3.0       6.0
```

Since P<0.05, then the moisture content is significantly different from soil to soil

LSD = $SE_{\text{difference of any two means replicates}}$ x $t_{\text{error df@5\%}}$

$$LSD = \sqrt{\frac{2 \ x \ Error_{MS}}{r}} \ x \ t_{\text{error df@5\%}}$$

$$= \sqrt{\frac{2 \ x 1.04}{3}} \ x \ 2.179$$

= 0.833

Treatment	Ho	Akatsi	Mampong	Wenchi	Akuse	KNUST
Mean	12.43	11.15	13.92	12.26	13.44	11.09

Mampong > Akuse > Ho > Wenchi > Akatsi >KNUST

pH

One-way ANOVA: Ho, Akatsi, Mampong, Wenchi, KNUST, Akuse

```
Source  DF      SS      MS      F      P
Factor   5  8.7115  1.7423  31.60  0.000
Error   12  0.6617  0.0551
Total   17  9.3732

S = 0.2348   R-Sq = 92.94%   R-Sq(adj) = 90.00%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level     N    Mean   StDev  -+---------+---------+---------+--------
Ho        3  5.3967  0.1450                          (---*---)
Akatsi    3  5.1800  0.1418                       (---*---)
Mampong   3  3.7600  0.0557   (----*---)
Wenchi    3  5.1900  0.3559                       (---*---)
KNUST     3  4.0933  0.3907       (---*----)
Akuse     3  5.6400  0.0854                             (----*---)
                             -+---------+---------+---------+--------
                            3.50      4.20      4.90      5.60

Pooled StDev = 0.2348


Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons

Individual confidence level = 99.43%


Ho subtracted from:

           Lower   Center    Upper  -------+---------+---------+---------+--
Akatsi   -0.8607  -0.2167   0.4273                (----*---)
Mampong  -2.2807  -1.6367  -0.9927    (---*---)
Wenchi   -0.8507  -0.2067   0.4373                (----*---)
KNUST    -1.9473  -1.3033  -0.6593      (---*----)
Akuse    -0.4007   0.2433   0.8873                   (----*---)
                                    -------+---------+---------+---------+--
                                        -1.5       0.0       1.5       3.0


Akatsi subtracted from:

           Lower   Center    Upper  -------+---------+---------+---------+--
Mampong  -2.0640  -1.4200  -0.7760     (----*---)
Wenchi   -0.6340   0.0100   0.6540                 (---*---)
KNUST    -1.7307  -1.0867  -0.4427       (----*---)
Akuse    -0.1840   0.4600   1.1040                    (---*---)
                                    -------+---------+---------+---------+--
                                        -1.5       0.0       1.5       3.0


Mampong subtracted from:

          Lower  Center   Upper  -------+---------+---------+---------+--
Wenchi   0.7860  1.4300  2.0740                      (----*---)
KNUST   -0.3107  0.3333  0.9773               (---*----)
Akuse    1.2360  1.8800  2.5240                         (----*---)
```

```
                              -------+---------+---------+---------+--
                                 -1.5       0.0       1.5       3.0


Wenchi subtracted from:

         Lower   Center    Upper  -------+---------+---------+---------+--
KNUST  -1.7407  -1.0967  -0.4527       (----*---)
Akuse  -0.1940   0.4500   1.0940                  (---*---)
                                  -------+---------+---------+---------+--
                                     -1.5       0.0       1.5       3.0


KNUST subtracted from:

        Lower  Center   Upper  -------+---------+---------+---------+--
Akuse  0.9027  1.5467  2.1907                          (---*----)
                               -------+---------+---------+---------+--
                                  -1.5       0.0       1.5       3.0
```

Since $P<0.05$, then the pH is significantly different from soil to soil

LSD = $SE_{\text{difference of any two means of 3 replicates}}$ x $t_{\text{error df@5\%}}$

$$= \sqrt{\frac{2\ x\ Error_{MS}}{r}}\ \text{x}\ t_{\text{error df@5\%}}$$

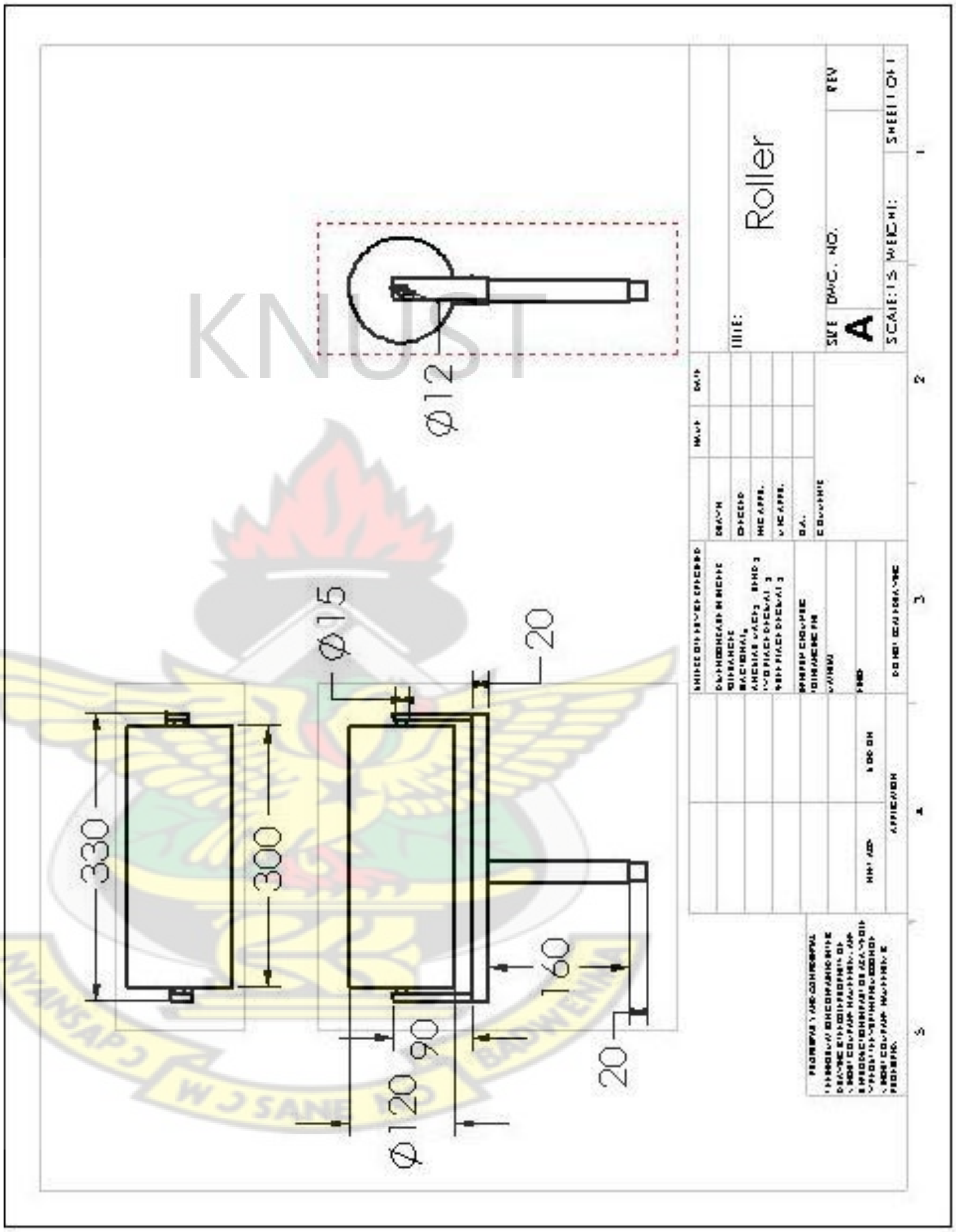
$$= \sqrt{\frac{2\ x 0.0551}{3}}\ \text{x}\ 2.179$$

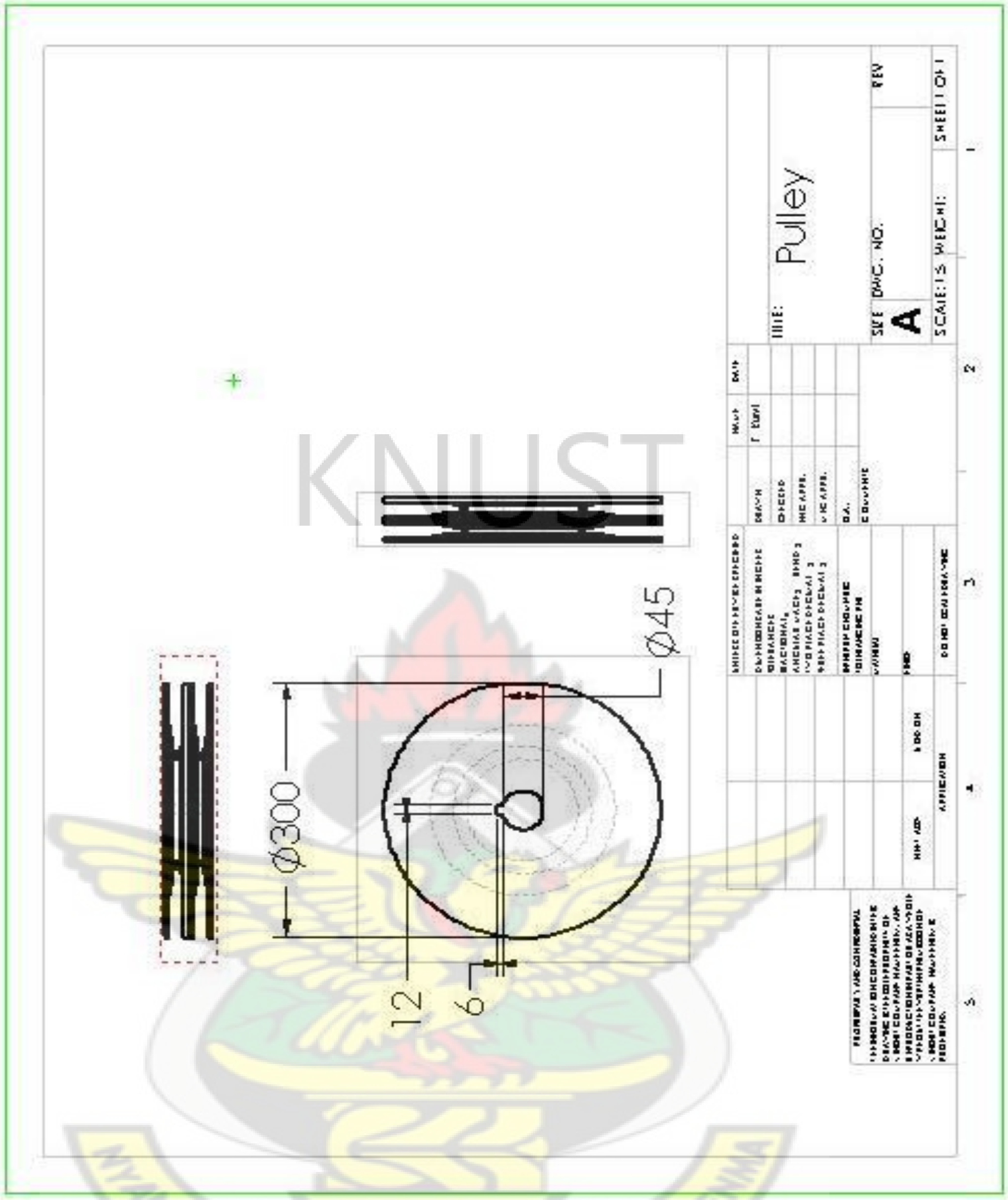
=0.4176

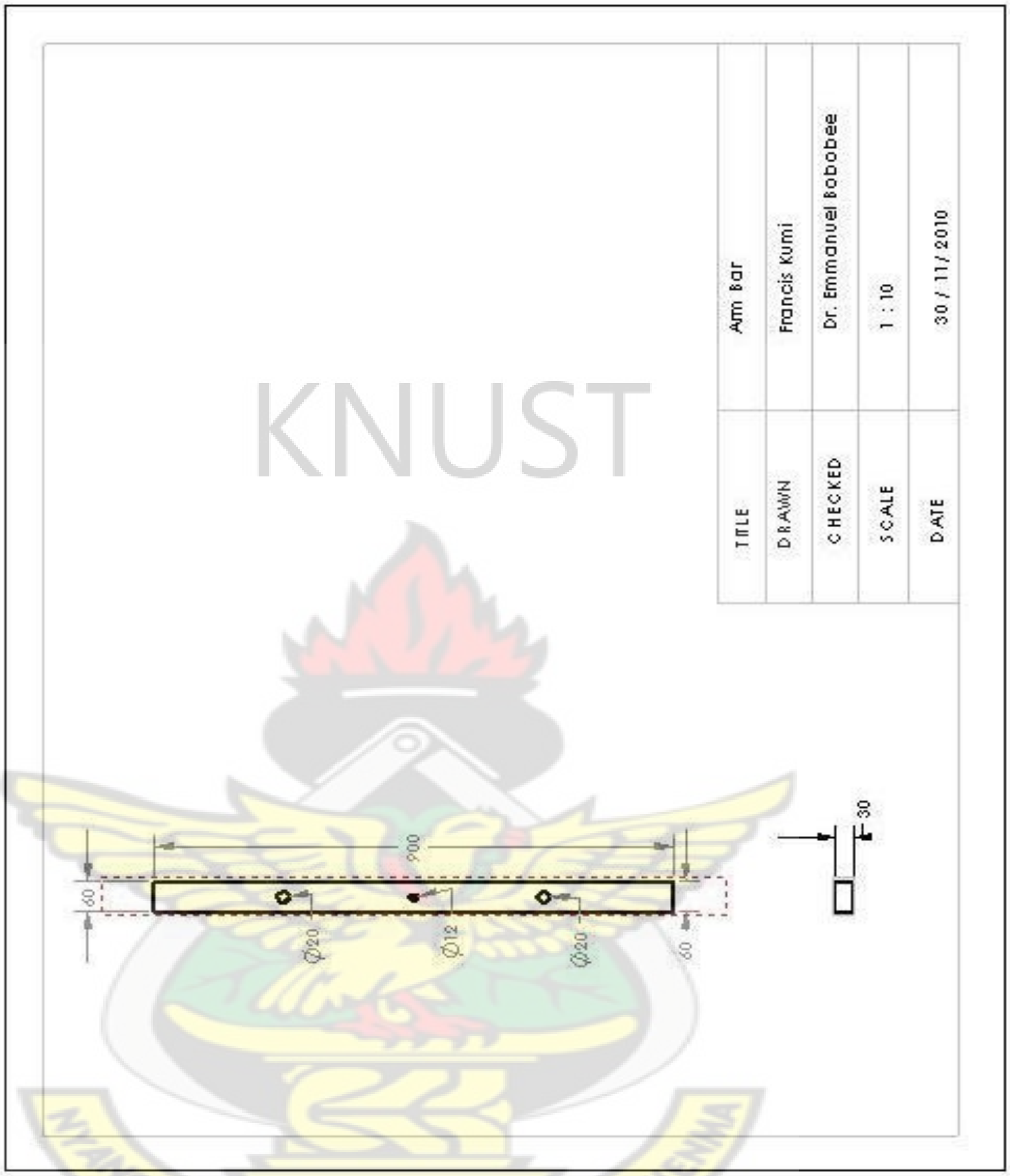
Treatment	Ho	Akatsi	Mampong	Wenchi	Akuse	KNUST
Mean	5.40	5.18	3.76	5.19	5.64	4.09

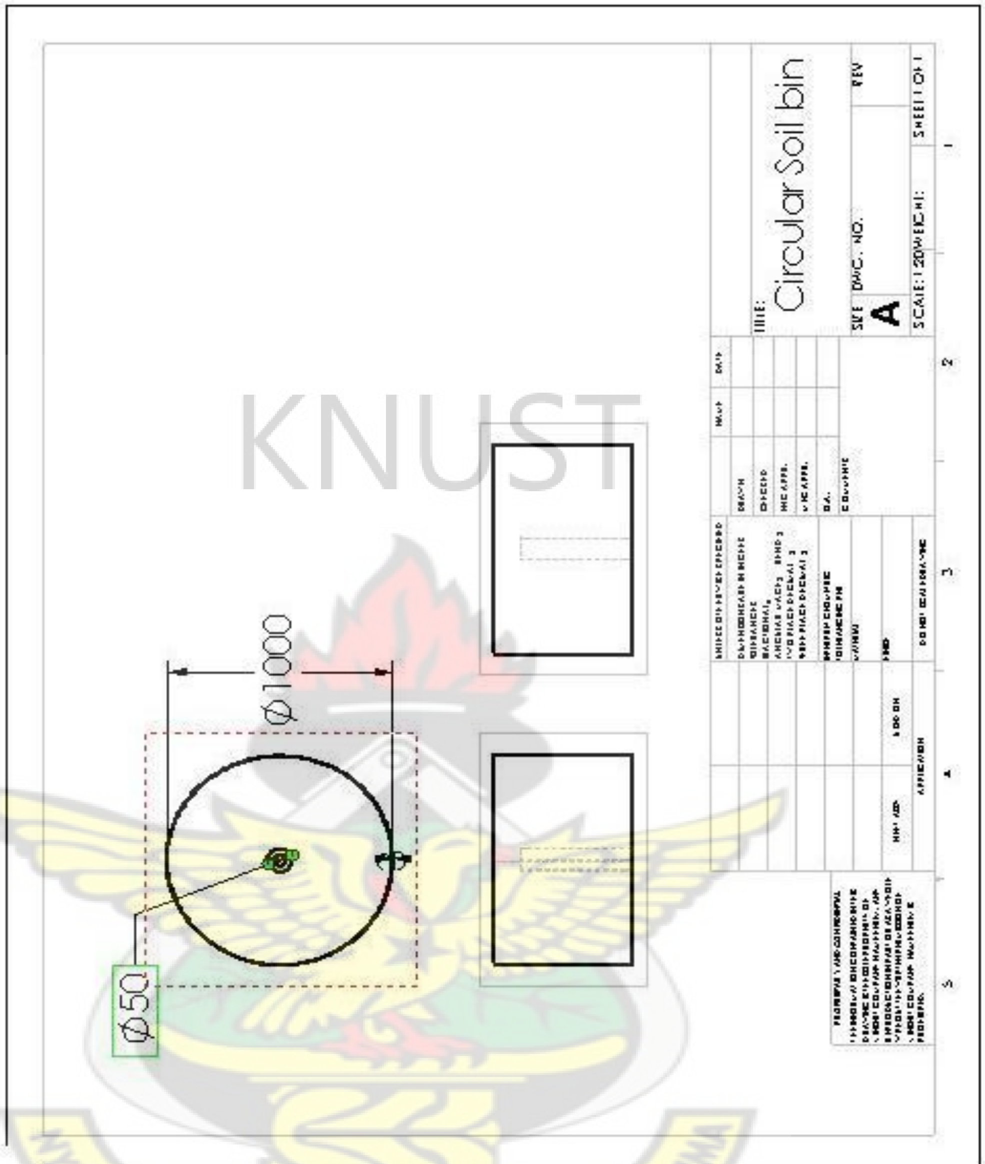
Akuse > Ho >Wenchi > Akatsi > KNUST > Mampong

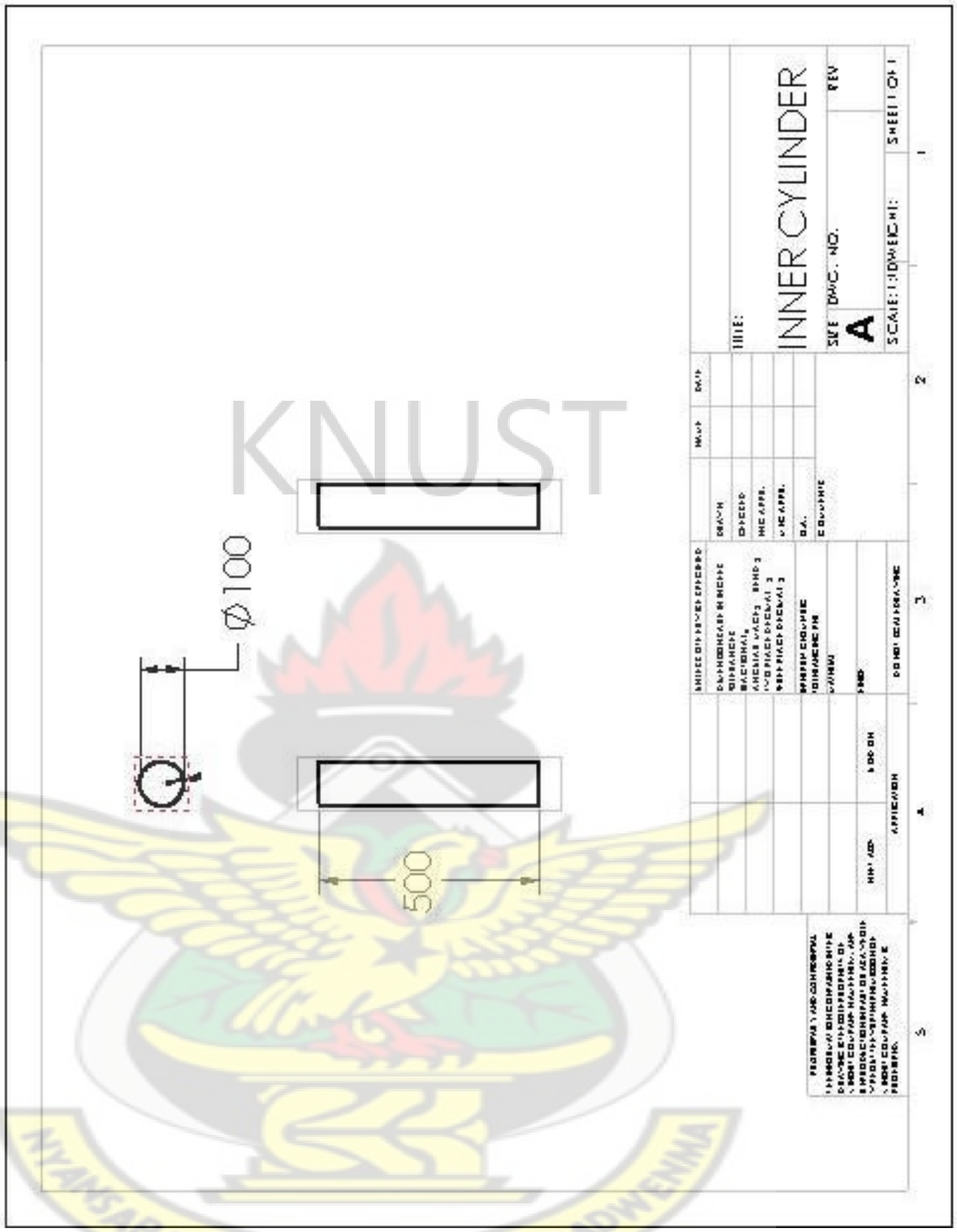
Appendix 2: Part Drawings

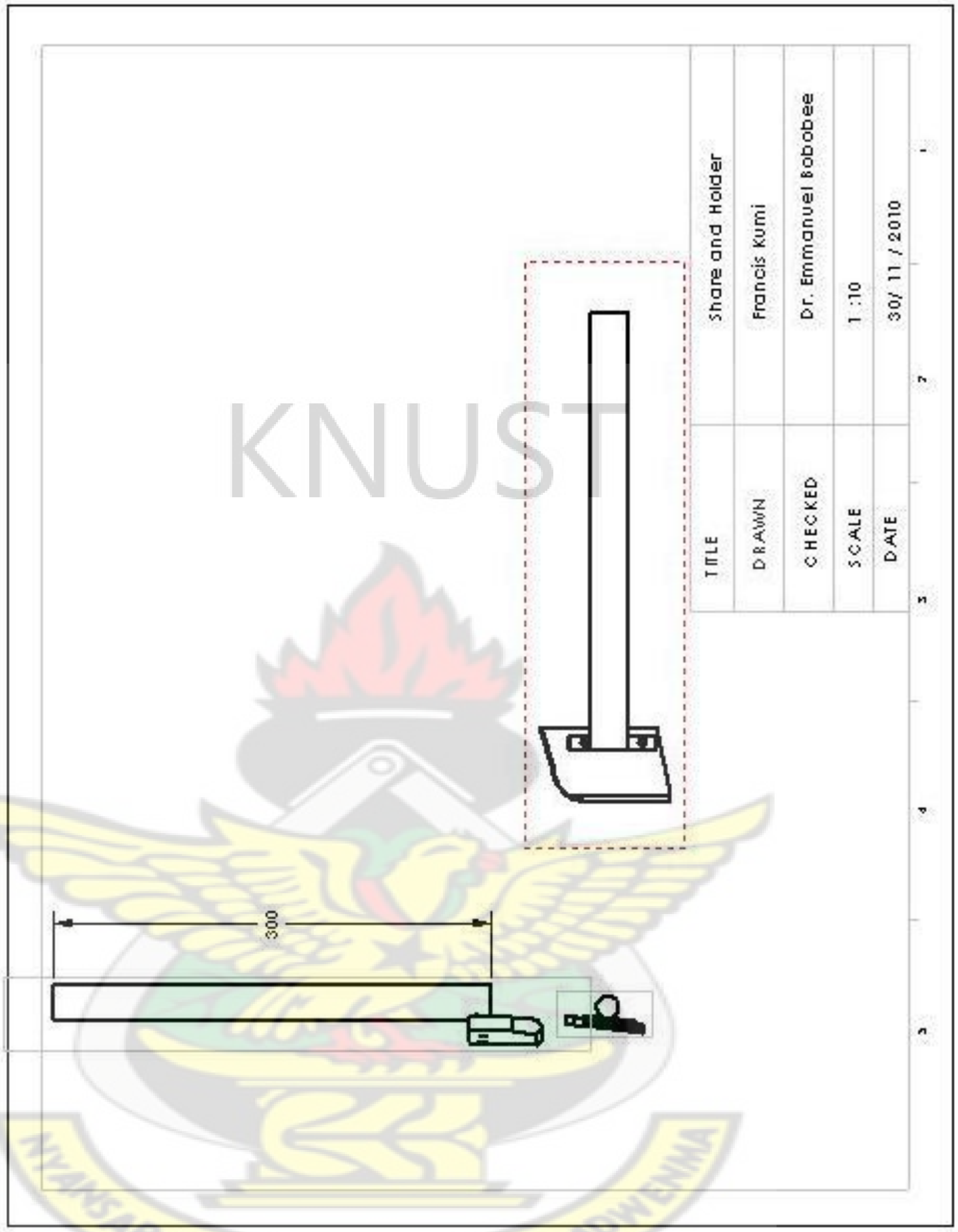


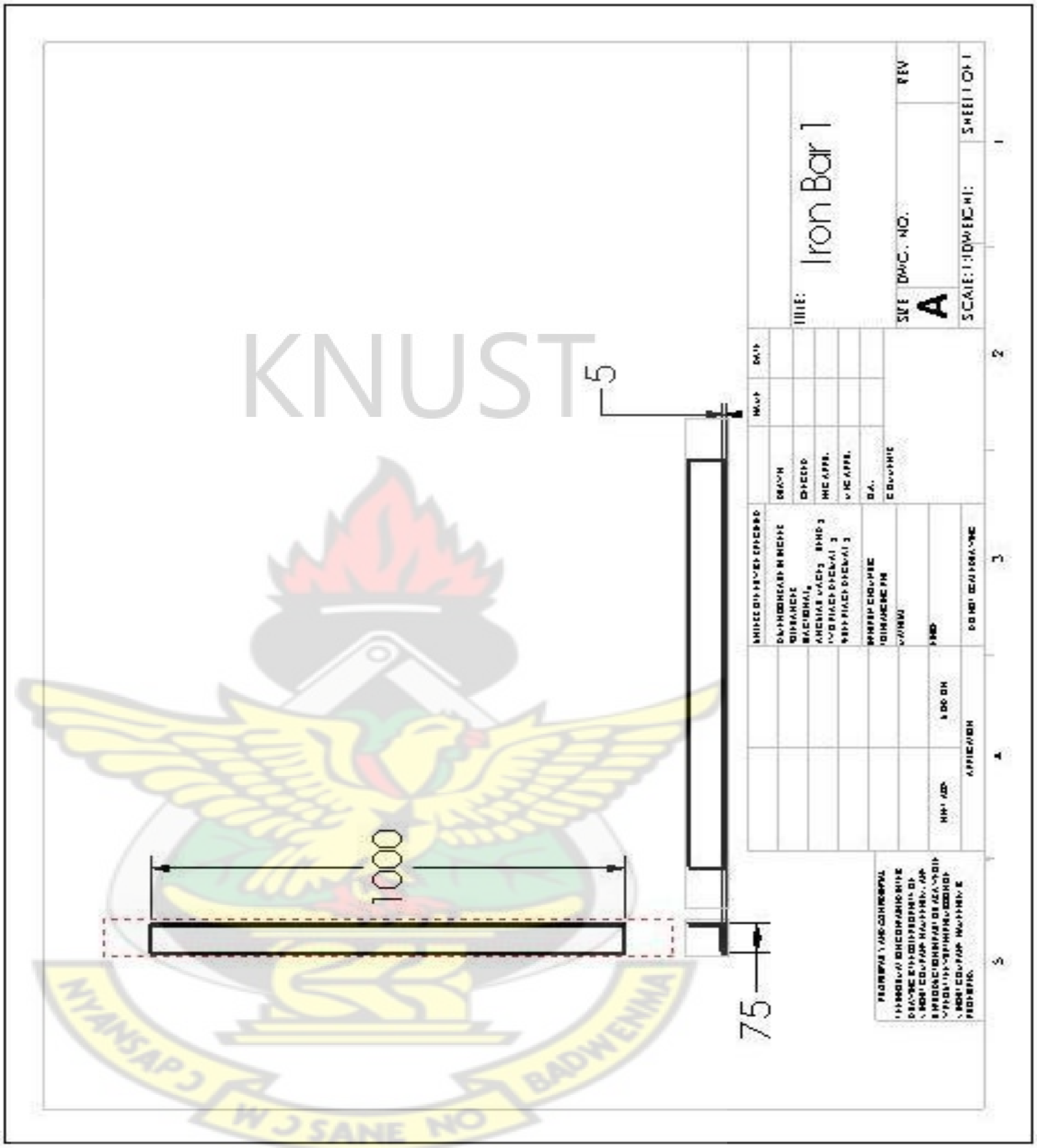

Ø300
Ø45
12
6
TITLE:
Pulley
SIZE
DWG. NO.
A
REV
SCALE:1:5
WEIGHT:
SHEET 1 OF 1

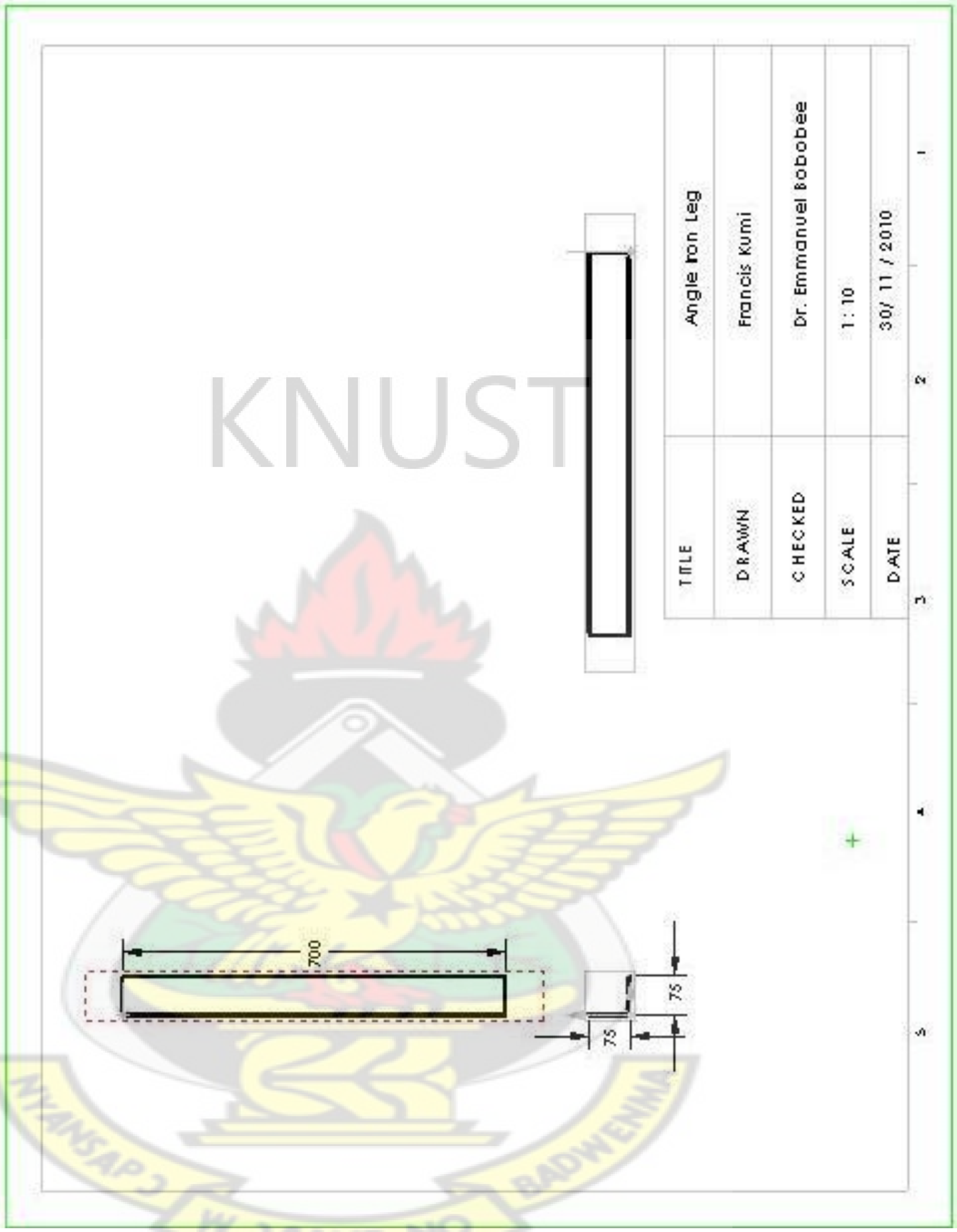

TITLE
Arm Bar
DRAWN
Francis Kumi
CHECKED
Dr. Emmanuel Bobobee
SCALE
1 : 10
DATE
30 / 11/ 2010
900
60
60
Ø20
Ø12
Ø20
30


Circular Soil bin
TITLE:
SIZE
DWG. NO.
A
REV
SCALE: 1:20
WEIGHT:
SHEET 1 OF 1
Ø1000
Ø50

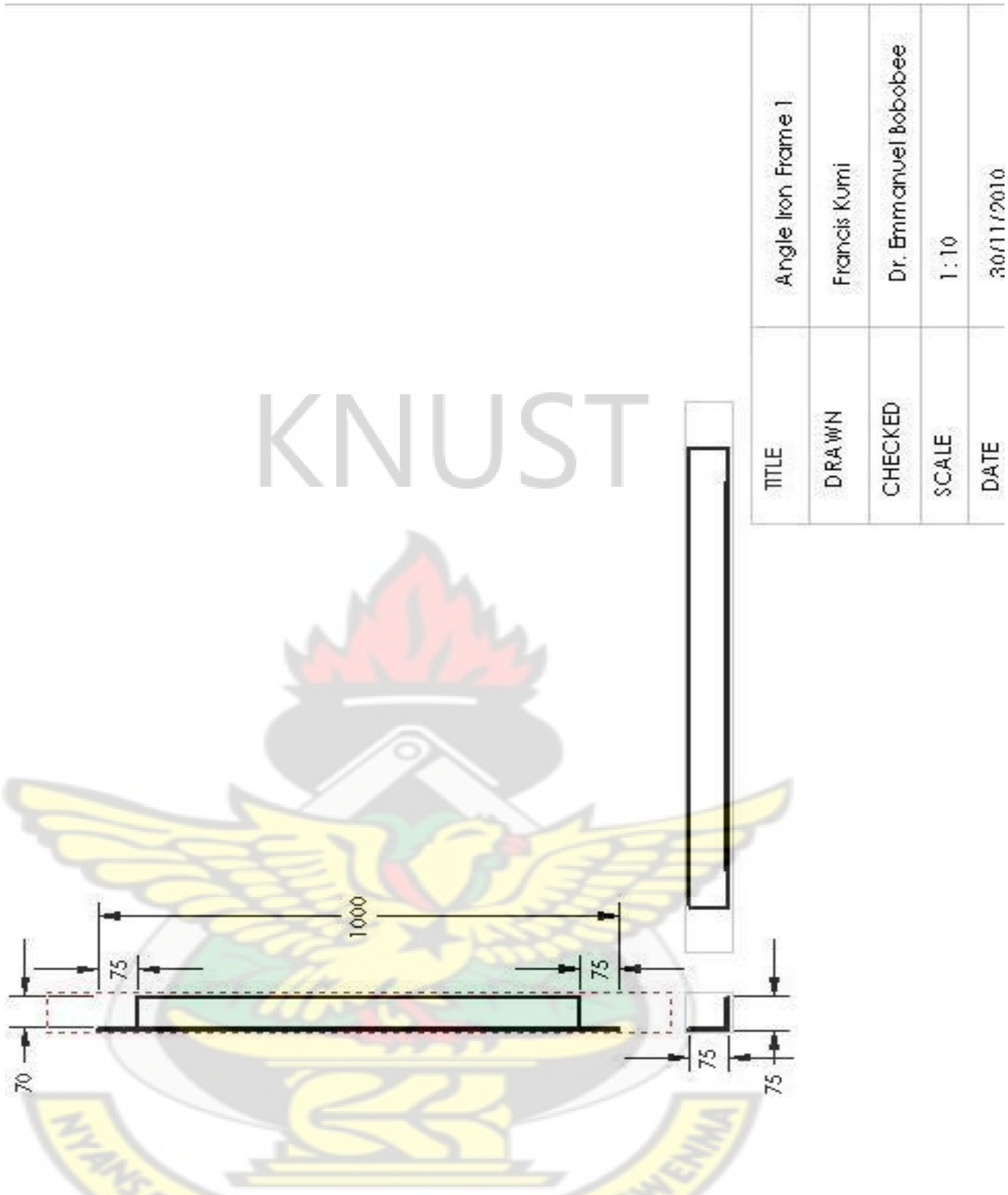

INNER CYLINDER
Ø100
500
TITLE:
SIZE
A
DWG. NO.
REV
SHEET 1 OF 1


TITLE
Share and Holder
DRAWN
Francis Kumi
CHECKED
Dr. Emmanuel Bobobee
SCALE
1 :10
DATE
30/ 11 / 2010
300

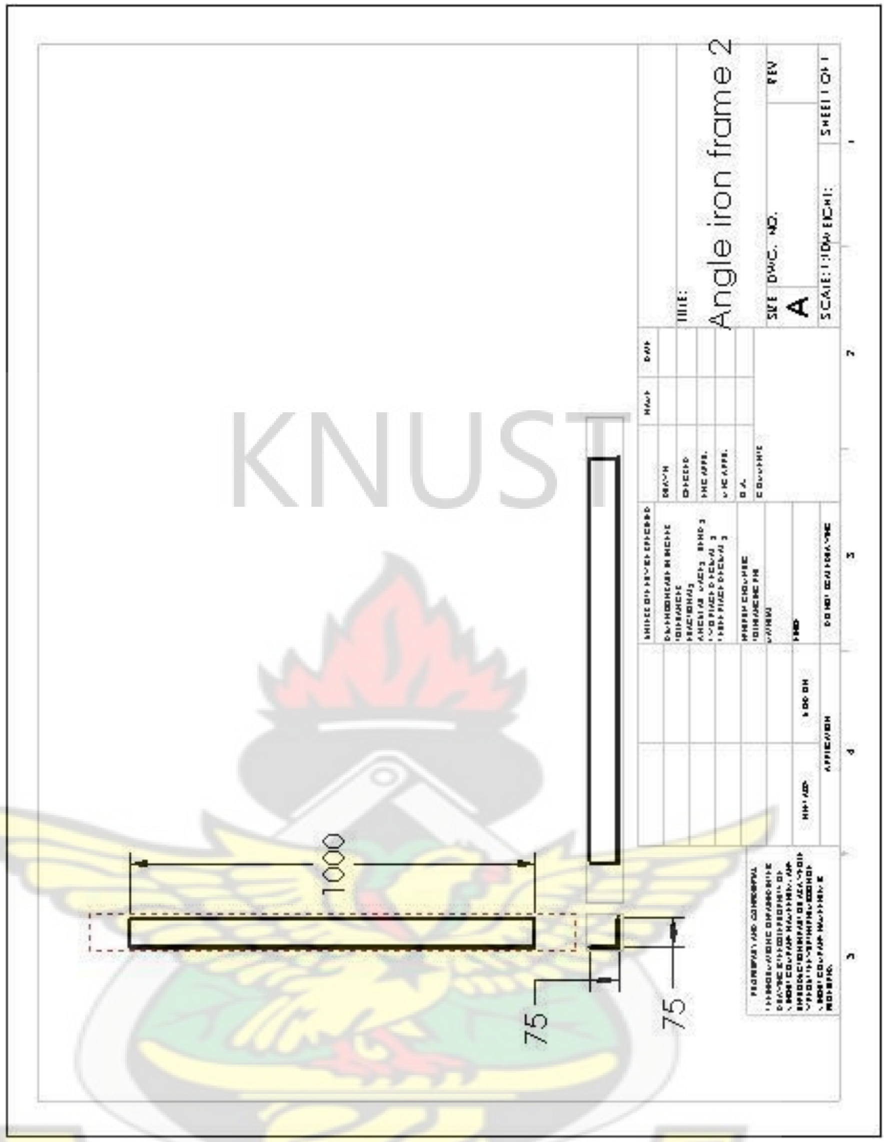

Iron Bar 1
TITLE:
SIZE
A
DWG. NO.
REV
SHEET 1 OF 1
1000
75
5

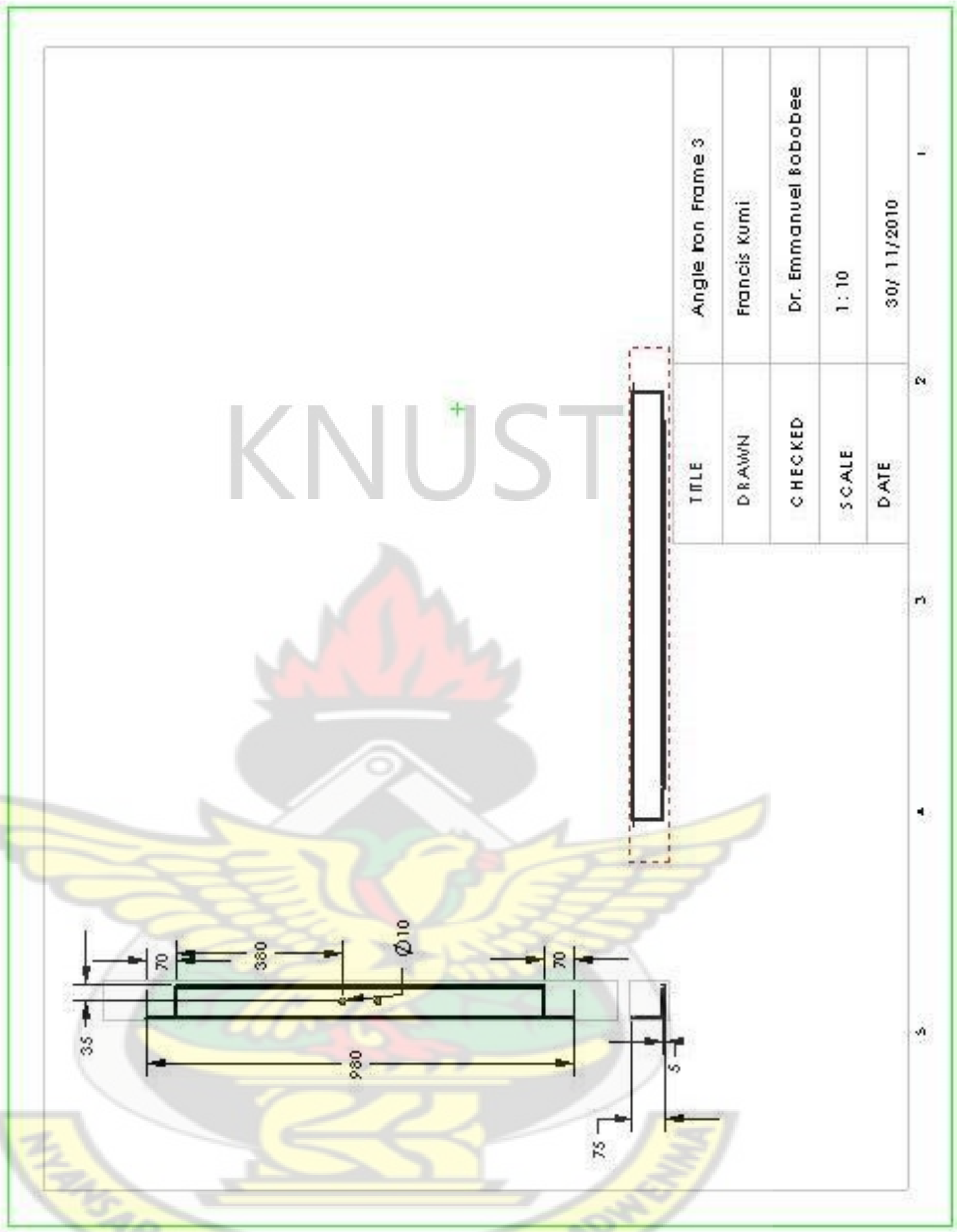


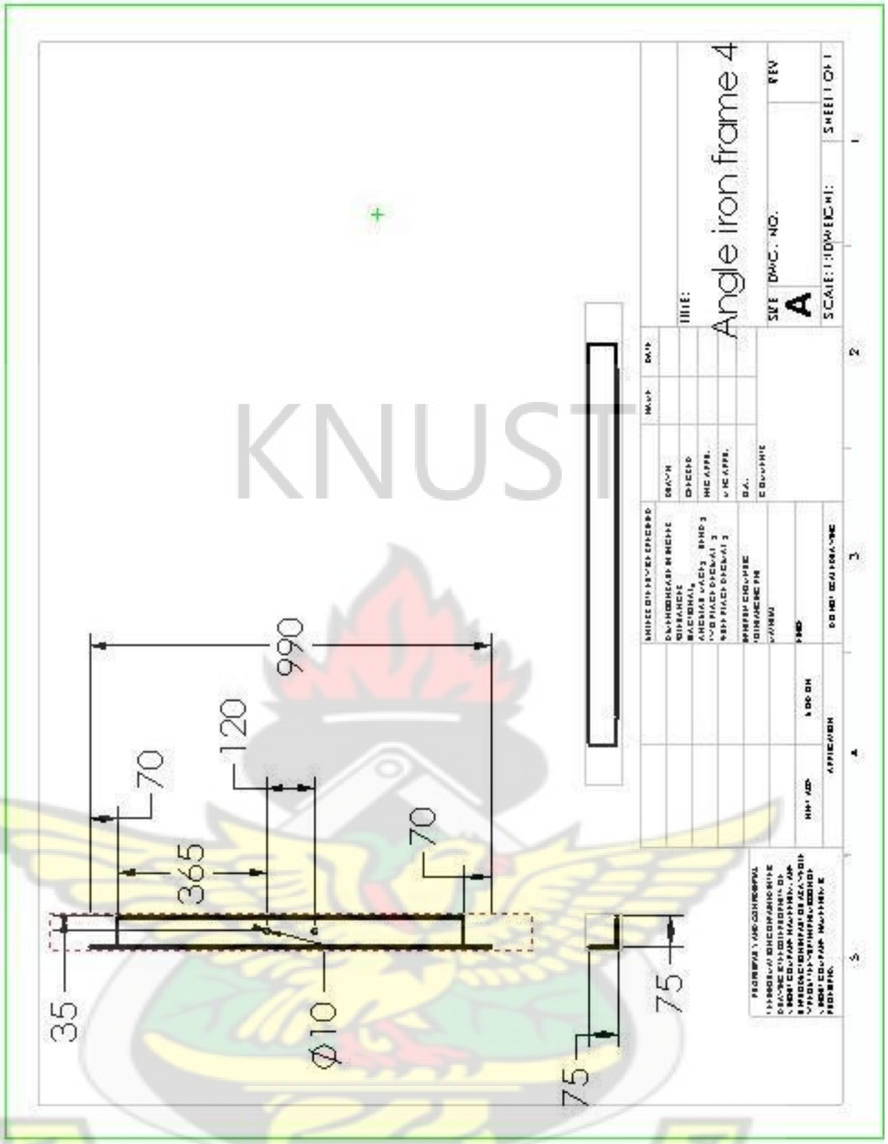
TITLE
Angle Iron Leg
DRAWN
Francis Kumi
CHECKED
Dr. Emmanuel Bobobee
SCALE
1 : 10
DATE
30/ 11 / 2010
700
75
75

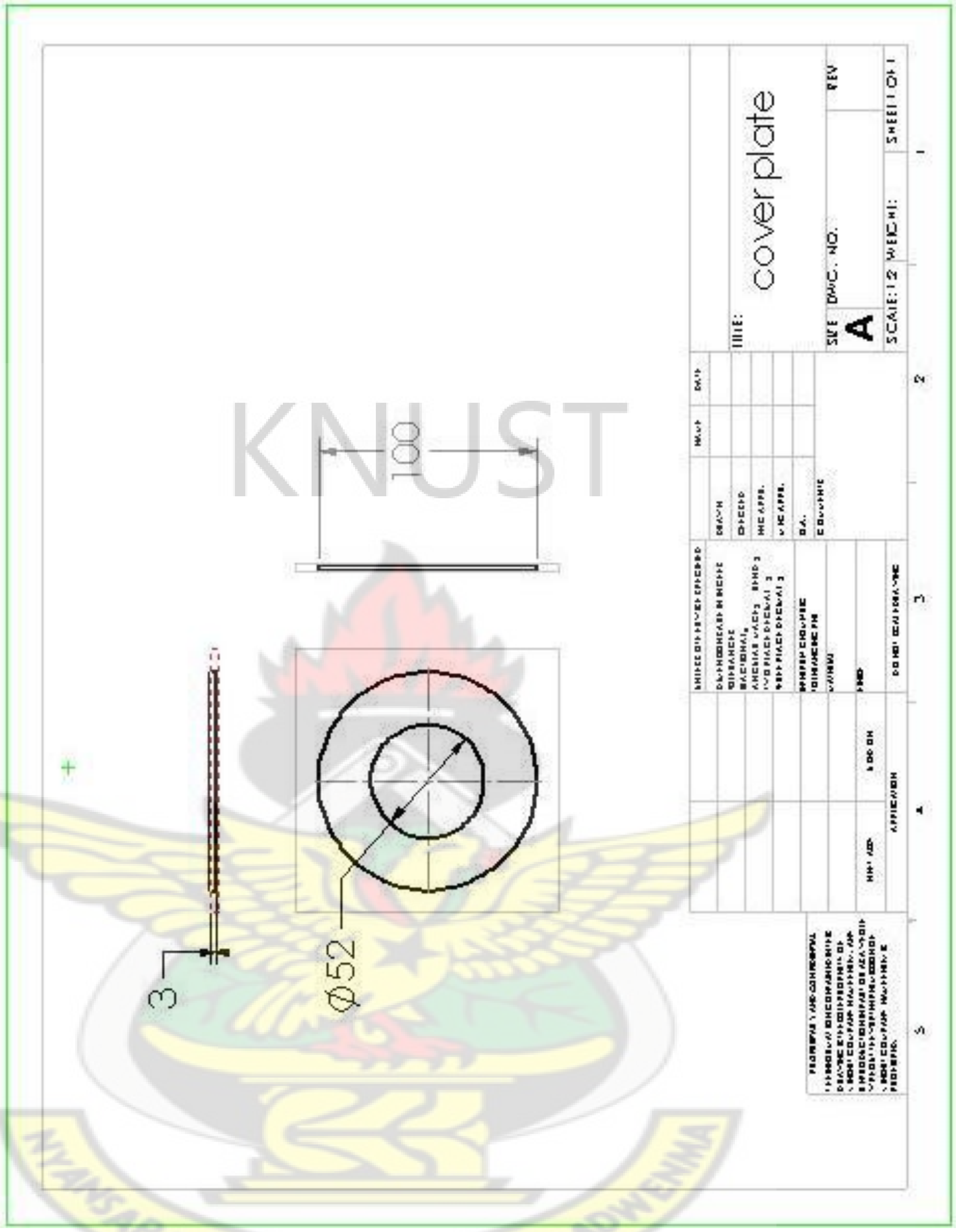


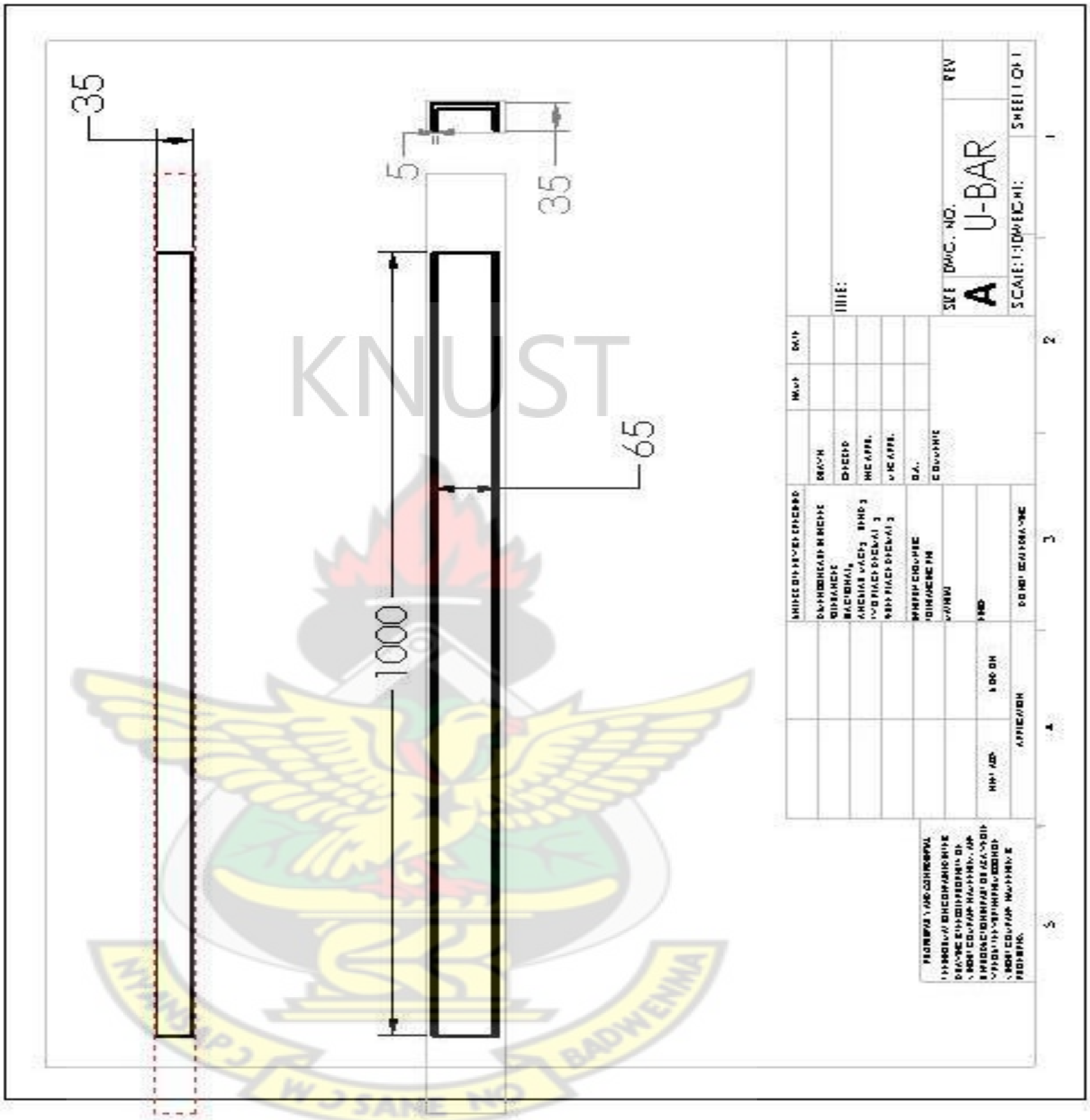
TITLE
Angle Iron Frame 1
DRAWN
Francis Kumi
CHECKED
Dr. Emmanuel Bobobee
SCALE
1:10
DATE
30/11/2010
1000
75
75
70
75
75

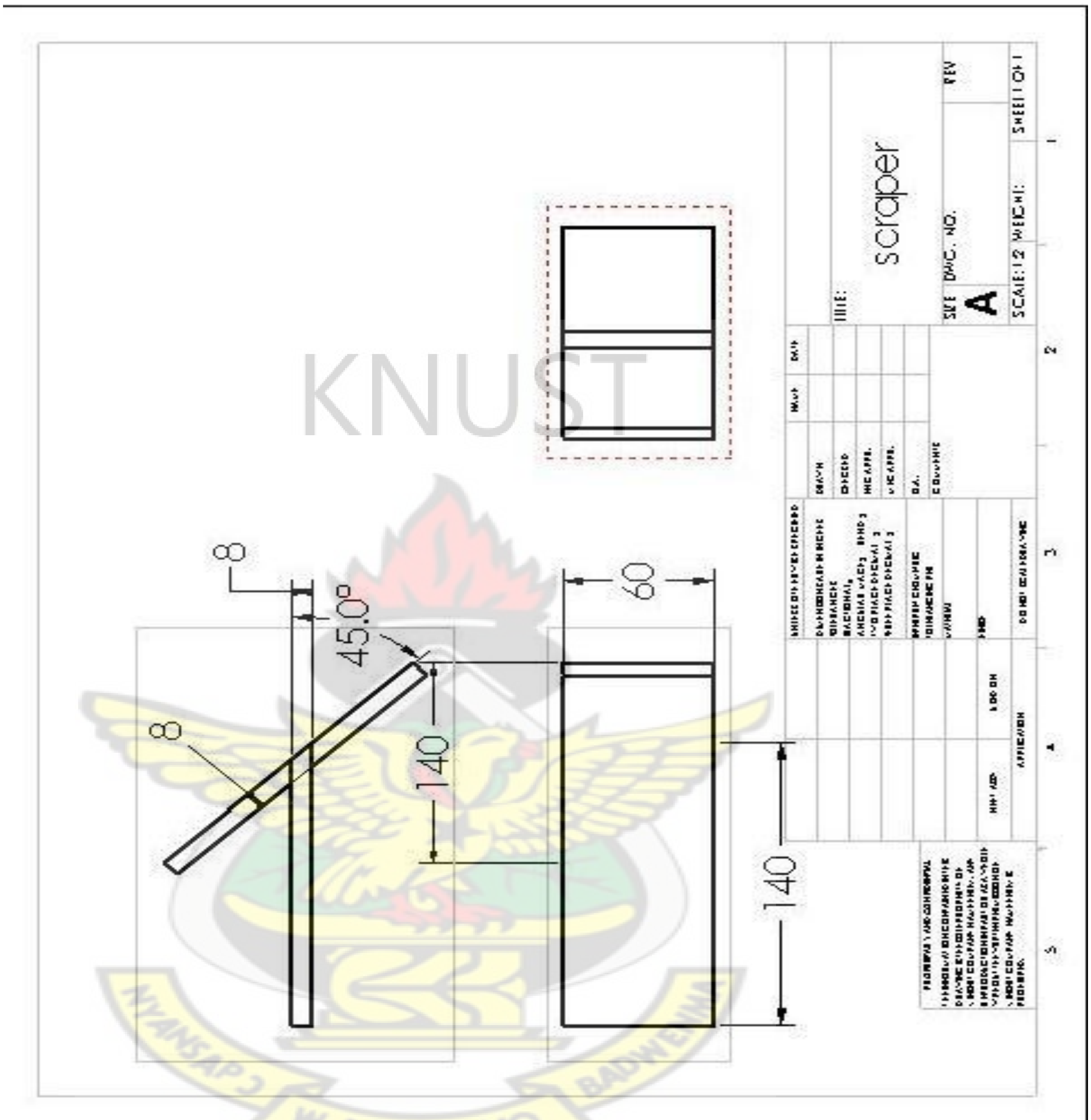

Angle iron frame 2
1000
75
75
A


TITLE
Angle Iron Frame 3
DRAWN
Francis Kumi
CHECKED
Dr. Emmanuel Bobobee
SCALE
1 : 10
DATE
30/ 11/2010
70
380
70
Ø10
35
980
75
5


Angle iron frame 4
TITLE:
SIZE
DWG. NO.
A
REV
990
120
70
365
70
35
Ø10
75
75

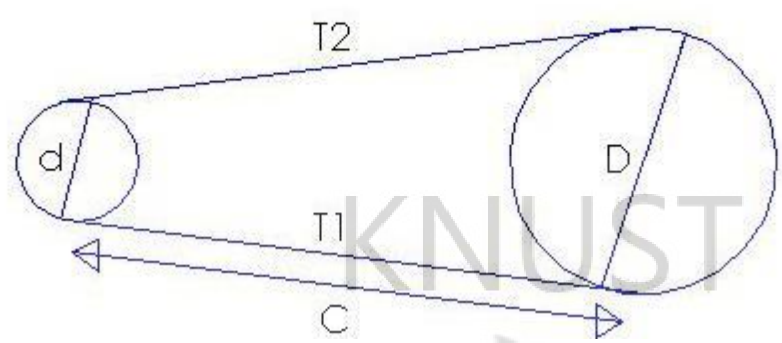

cover plate
TITLE:
SIZE
A
DWG. NO.
REV
SCALE:1:2
WEIGHT:
SHEET 1 OF 1
100
Ø52
3


35
5
35
1000
65
SIZE
A
DWG. NO.
U-BAR
REV
SHEET 1 OF 1


8
8
45.0°
140
60
140
TITLE:
scraper
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

Appendix 3: **Design Calculations and Bill of Quantities**

Belt Design



Determination of length of belts

$$L = 2C + \frac{\pi}{2}(D + d) + \frac{(D - d)^2}{4C}$$

C= 615mm

D= 300

d= 100

$$L = 2(615) + \frac{\pi}{2}(300 + 100) + \frac{(300 - 100)^2}{4(615)}$$

L= <u>1874mm</u>

=<u>1.874m</u>

Arc contact, $\beta = 180^\circ - 60^\circ(D-d)/C$

$\beta = 180^\circ - 60^\circ(0.3-0.1)/1.874$

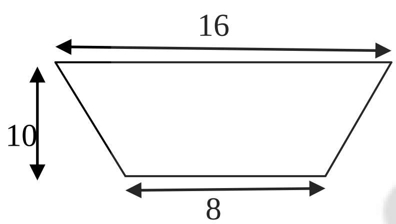
$\beta = 173.6^\circ$

Design for Belt

Speed, $V = \frac{\pi d N}{60}$

$= \frac{\pi(0.1)(1440)}{60}$

$= 7.54 \ ms^{-1}$



Area of of belt ,A = $\left(\frac{16+8}{2}\right)$x 10

$=120 \ mm^2$

$= 120 \times 10^{-6} m^2$

Mass of belt/length(m) = Area x length x density

$= 120 \times 10^{-6} \times 1.874 \times 1200$

= 0.269856kg/m

Centrifugal tension, $T_c = MV^2 = 0.269856(7.54)^2$

= 15.34 N

Maximum tension, T = maximum safe stress in material (f) x Area

$= 7 \times 10^6 \times 120 \times 10^{-6}$

= 840 N

Tension on tight side of the belt, $T_1 = T - T_c$

T_1= 840 -15.34 = 824.66 N

T= 825 N

Tension on slack side, $T_2 = \frac{T_1 - MV^2}{C_1} + MV^2$

$T_2 = \frac{824.66 - 0.269856(7.54)^2}{1.874} + 0.269856(7.54)^2$

T_2= 447.40N

T= 447N

Power transmitted by the belt, P = (T_1 –T_2) V x n, where n=number of belts

P=(825 – 447) 7.54 x 2

P= 5700.24W

P= 5.7kW

Shaft Design

$T = \frac{60P}{2\pi N}$

P=15 kW= 15000W

N= 40 rpm

$T = \frac{60 \, x 15000}{2\pi(40)}$

= 3581 N-m

= 3581000 N-mm

Bending Moment

$M = \frac{WL}{4}$

W =21.84kg x 9.81ms^{-2}

= 214.25 N

$M= \frac{214.25 X 1.1}{4}$

= 58.92 N-m

= 58920 N-mm

$T_e = \sqrt{(Km . M)^2 + (Kt . T)^2}$

$= \sqrt{(1.5 \text{ x } 3581000)^2 + (1 \text{ x}58920)^2}$

= 540.372 x10^3 N-mm

$M_e = [\frac{1}{2}(K_m M + \sqrt{(Km . M)^2 + (Kt . T)^2})]$

$M_e = [\frac{1}{2}(1.5 \text{ x } 3581000 + \sqrt{(1.5 \text{ x}3581000)^2 + (1 \text{ x}58920)^2})]$

= 228.612 x 10^3 N-mm

$\sqrt{M^2 + T^2} = \frac{\pi \tau {d_s}^3}{16}$

$\sqrt{(3581000)^2 + (58920)^2} = \frac{\pi \text{ x } 215 \text{x } {d_s}^3}{16}$

$d^3 = \frac{57303755}{\pi \text{ x } 215}$

d^3 = 84838.85

d = 43.9 mm

Therefore choosing the shaft diameter of 50mm was safe

Roller Design

Weight of roller subassembly = 9.2 kg

Force exerted by roller = 9.2 x 9.81 = 90.252 N

Total circumference of roller = πD = π x 0.125m

=0.393m

Length of contact with soil at a time = 3 cm=0.03

Area of contact with the soil = Length x Breadth

= 0.3 x 0.06 = 0.009 m^2

Pressure of roller = 90.252 N / 0.009 m^2

= 10028 N/ m^2 = 10028kPa = 10.028 kPa

=10 kPa

Design for the support frame

Mass of the empty soil bin = 442.1kg

Average Mass of soil = Density (wet bulk) x Volume

= 2.05 x 10^3(kg/m^3) x π (0.5 m)^2 x 0.17m

= 273.711 kg

Mass of shaft = 21.84 kg

Mass of arm bar = 12.64 kg

Mass of 2 u-bars = 12.87 kg

Mass of roller =9.2 kg

Therefore total mass of top assembly supported by the frame= 442.1 + 273.71 + 21.84 + 12.64 + 12.87 +9.2 = 772.36 kg

Total force on the frame, F= 772.36 x 9.81 =7576.85N

The weight of all the other members the frame would support were considered in the design of the frame. A 5 x75x75 mm angle iron having a Young Modulus of 20 GN/m^2 was chosen. The compressive stress on the frame is given as D_c = F/(4A)

Where F= Force= 7576.85 N

A= cross-sectional area of each frame leg

= 0.075 x0.075 =0.005625 m^2

D_c = 7576.85/(4 x 0.005625)

= 336.75kN/m^2

The calculated value is much less than the Young Modulus (20 GN/m^2) of the angle irons. Therefore there will be no bending of the frame.

Soil Mechanics

Description	Design Parameter
Width of blade	350 mm
Depth of tine from soil surface(d)	100 mm
*Dry bulk density (ɤ)	17kN/m^2
*Cohesion (C)	10kN/m^2
*Surcharge (q)	0 kN/m^2
Rake Angle (α)	45 °
*Angle of soil-soil friction(ϕ)	30 °
*Angle of soil-metal friction (δ)	22 °

*** (Assumptions made from Wheeler and Godwin (1996) and Godwin *et a l*(1984))**

$$H = (ɤd^2 N_ɤ + CdN_c + qdN_q)w$$

$$N_{ɤ=\delta} = N_{\delta=0}\left[\frac{N_{\delta=\phi}}{N_{\delta=0}}\right]^{\delta/\phi}$$

$$= 0.95\left(\frac{1.6}{0.95}\right)^{22/30}$$

$$=1.39$$

$$N_{cɤ=\delta} = N_{c\delta=0}\left[\frac{N_{\delta=\phi}}{N_{\delta=0}}\right]^{\delta/\phi}$$

$$= 0.825\left(\frac{2.9}{0.825}\right)^{22/30}$$

$$= 2.07$$

$$N_{q\gamma=\delta} = N_{q\delta=0}\left[\frac{N_{\delta=\phi}}{N_{\delta=0}}\right]^{\delta/\phi}$$

$$= 1.9\left(\frac{3.4}{1.9}\right)^{22/30}$$

$$= 2.91$$

$H = ((17x\ (0.1)^2 x\ 1.39) + (10\ x\ 0.1x2.07) + (0x0.1x2.91))\ x0.35$

= (0.2363 + 2.07 +0) x 0.35

= 0.80721 kN

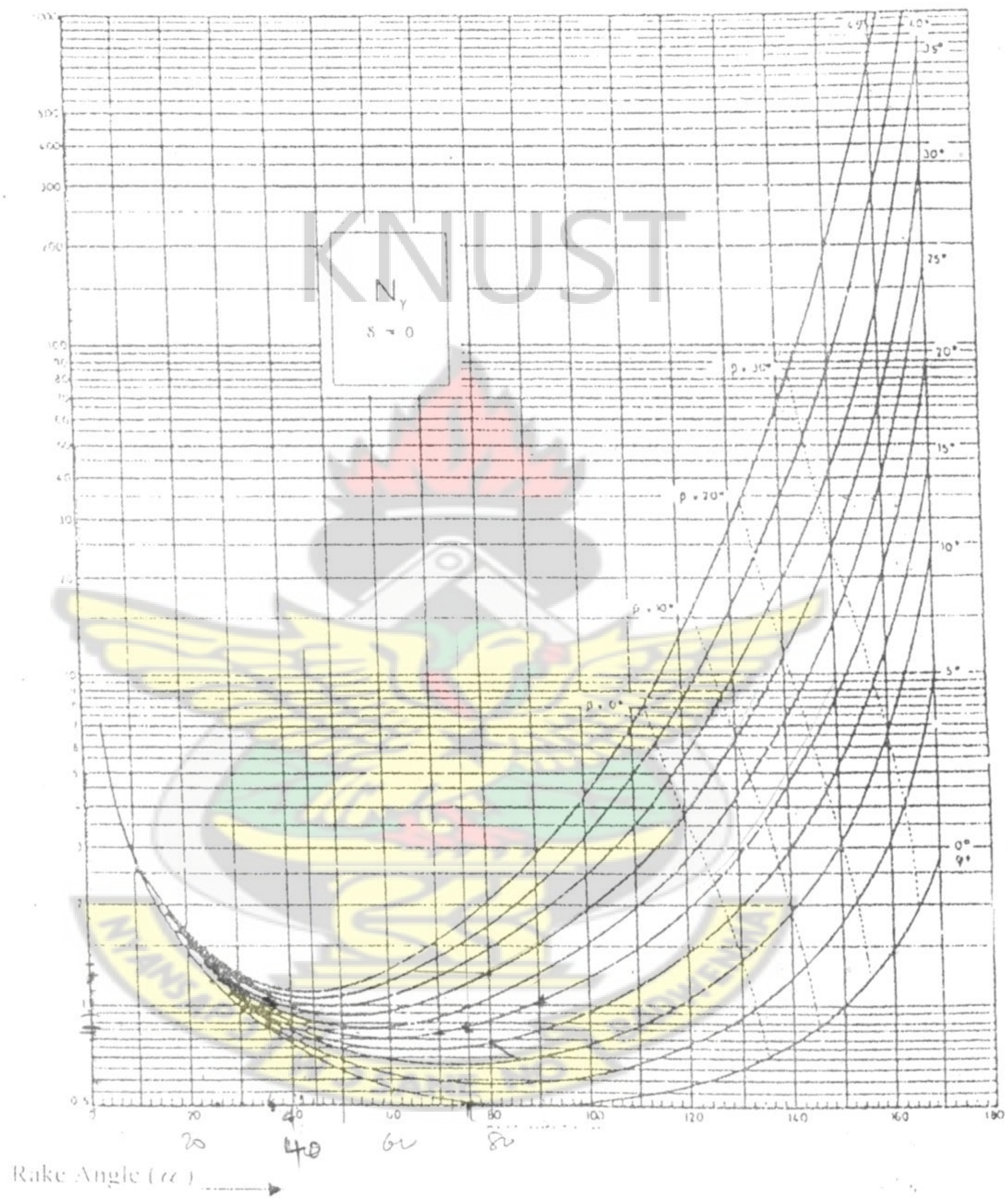
= 807.21 N

Bill of Quantities

Name of Part	Dimension/Description	Material	Q'ty	Cost(GH₵)
Angle Iron	5 x 75 x75mm	Mild Steel	2	190
Sheet Metal	3 mm thickness	Mild Steel	2	220
Pulley	300 mm	Aluminium	1	30
	100 mm	Aluminium	3	75
U-bar	5 x 65 x 2000 mm	Mild Steel	1	80
Shaft	50 mm dia; 1100 mm length	Mild Steel	1	280
	30 mm dia; 160 and 300 mm length	Mild Steel	2	160
Arm bar	30 x 60 x 900 mm	Mild Steel	1	40
v-belt	B-75; 1874 mm length	Rubber	4	30
Ploughshare	12 X 100 x 350 mm	Cast-Steel	6	180
Bolt	M12 X 50 mm	Hardened Steel	8	8
Nut	M12	Hardened Steel	8	4
	M20	Hardened Steel	4	4
Flat Washer	M12	Hardened Steel	8	4
	M20	Hardened Steel	4	4
TOTAL	**-**	**-**	**55**	**1,309**

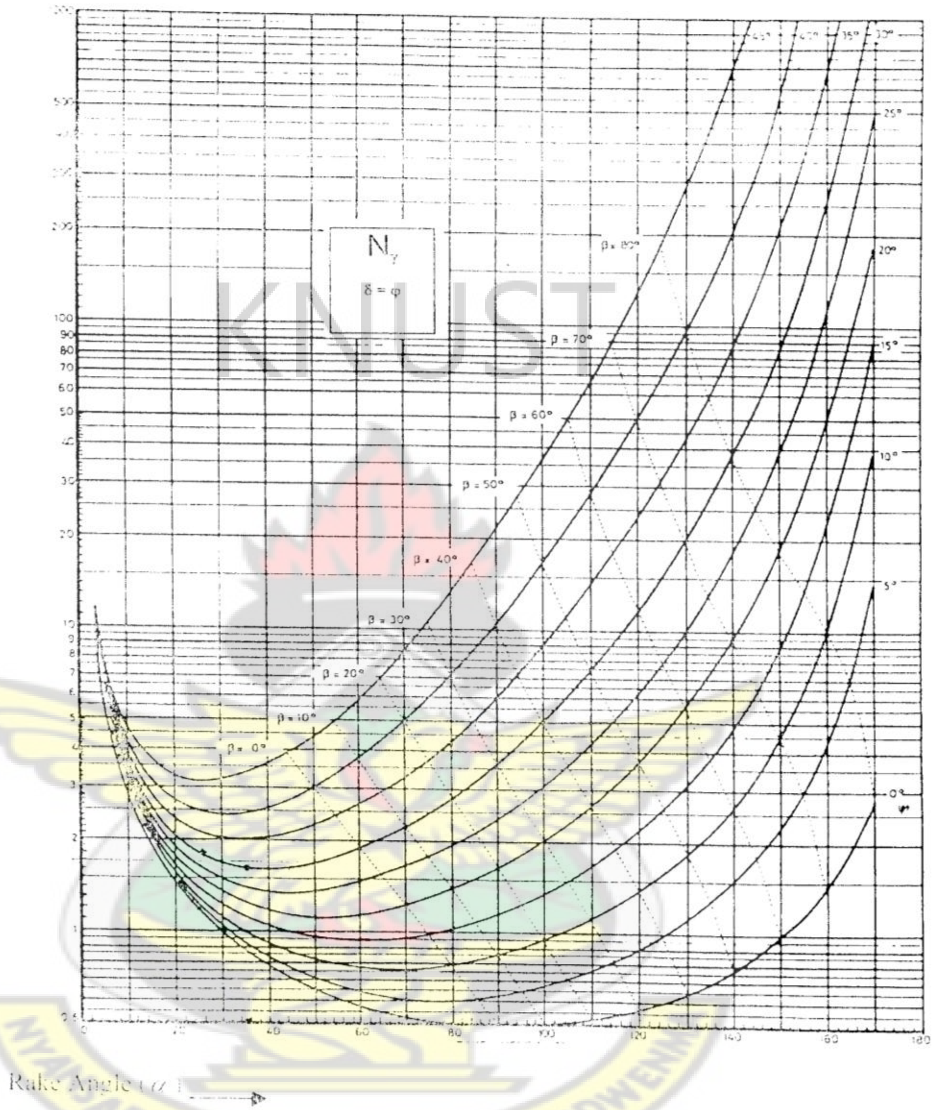
Appendix 4: N-factor Charts

GRAVITATIONAL: Smooth



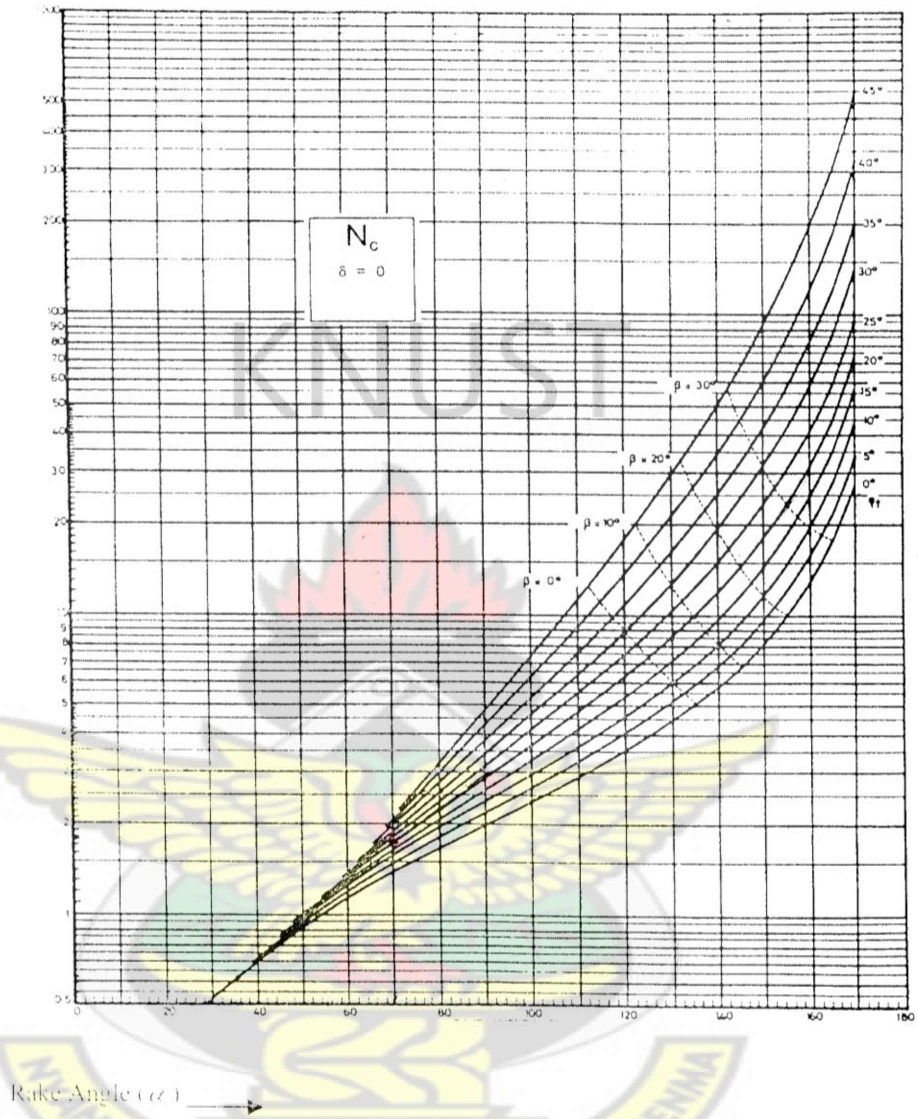
Source: Hettiarachi *et al*, 1966; Hettiarachi and Reece, 1974

GRAVITATIONAL: Rough



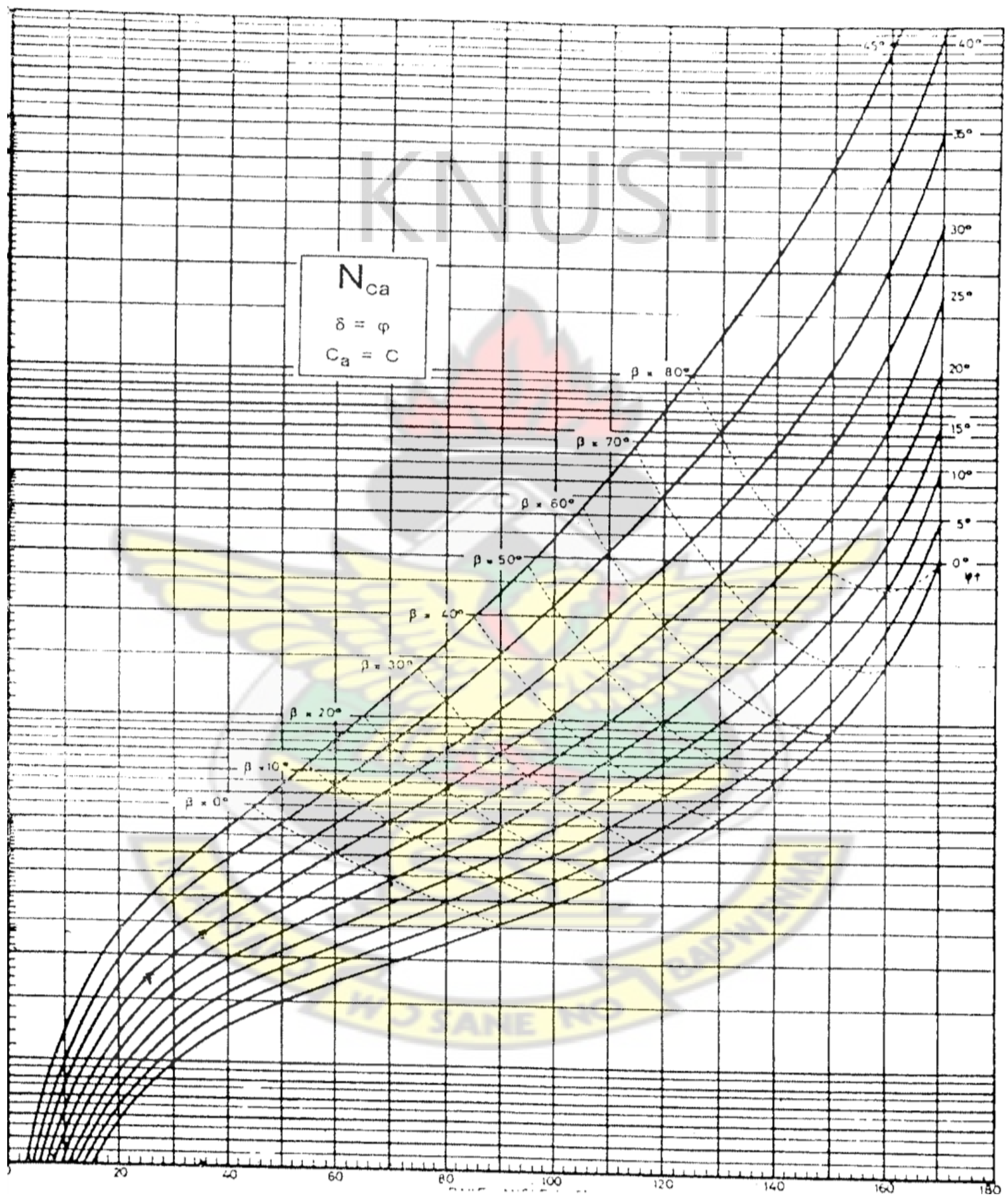
Source: Hettiarachi *et al*, 1966; Hettiarachi and Reece,1974

COHESIVE: Smooth



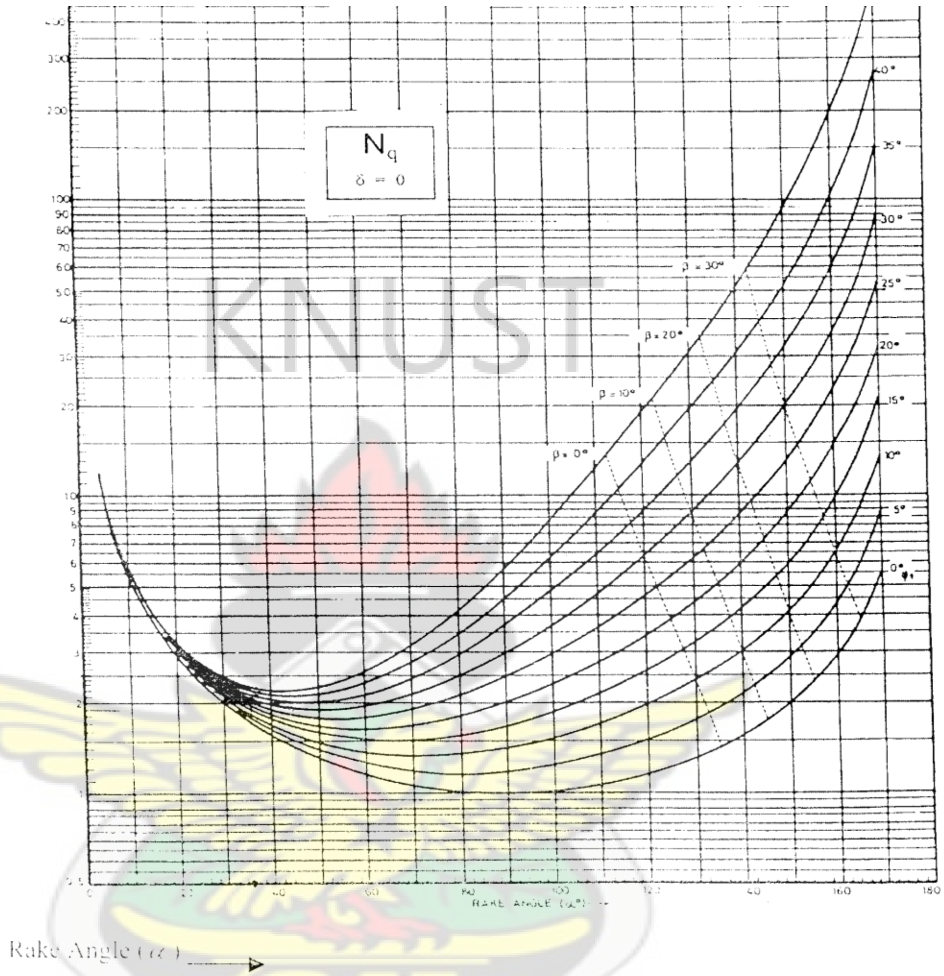
Source: Hettiarachi *et al*, 1966; Hettiarachi and Reece, 1974

COHESIVE: Rough



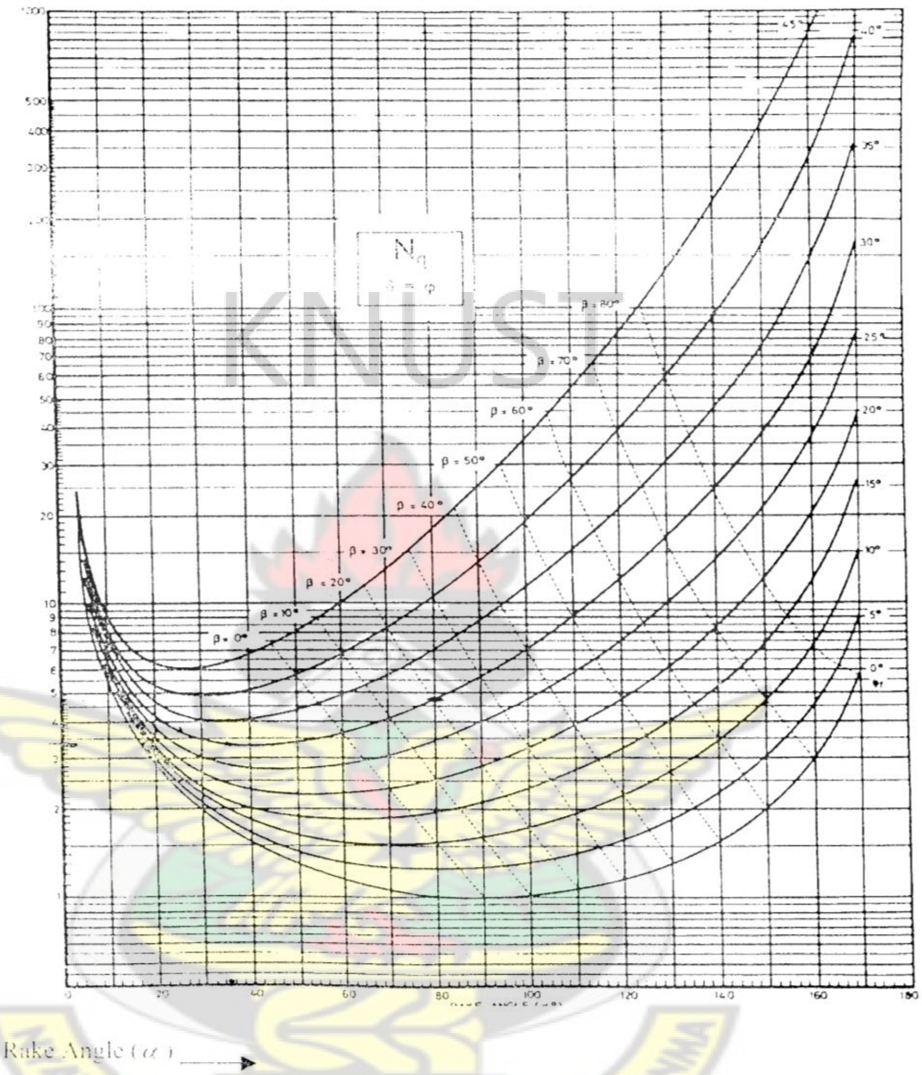
Source: Hettiarachi *et al*, 1966; Hettiarachi and Reece, 1974

SURCHAGRGE: Smooth



Source: Hettiarachi et al, 1966; Hettiarachi and Reece, 1974

SURCHARGE: Rough



Source: Hettiarachi *et al*, 1966; Hettiarachi and Reece, 1974