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Bone machining: An analysis of machining parameters such as cutting speed, feed rate, and depth of cut using bovine bone

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KEYWORDS

Bone machining
Bovine bone
Machining parameters
Cutting speed
Feed rate

ABSTRACT

Orthopedic surgery has become a predominant trend in surgery in present era. It deals in the modification of bones and cartilages through machining processes. The present research work deals in bone machining as a machining method with bovine bone as a piece of work material. Our main motive is on evaluating the consequences of three machining parameters, that is, cutting speed, feed rate, and depth of cut, to machining responses, that is machining time and surface roughness resulted by the turning, drilling, milling. The processes were operated at various cutting speeds (700 - 950 m/min), depths of cut (0.25 - 4 mm), and feed rate (50 – 400 mm/rev). Observation using the developed empirical models found that within the range of machining parameters evaluated, the most influential machining parameter to the cutting force is depth of cut, followed by feed and cutting speed. For surface roughness, feed is the most significant machining condition, followed by cutting speed, and with a depth of cut deliberated with minimum effect. The finest surface end was obtained at rock bottom cutting speed and feed setting. It was also found that milling process make minimum impact on the surface morphology leading it to be the better option in compared to the two process.

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1.0 INTRODUCTION

When a person experiences a bone failure (also referred to as a fracture), it’s important that the bone may heal properly in its original position in appropriate time. There are several treatments for a failure bone, then a orthopedic recommends is predicated upon major factors. These may include how severe the break is and where it's based on the swelling in a victim area. While some bones can heal by wearing a cast, others may require more invasive treatments, like bone fracture repair etc. Bone fracture repair may be surgery to repair a broken bone using some biomedical related parts with an assured biocompatibility of related metal screws, pins, rods, or plates to carry the bone in situ. It’s also referred to as open reduction and internal fixation (ORIF) surgery. Modern surgery has industrialized to such an extent that the body of data and technical skills required have led to surgeons specializing especially areas, usually an anatomical area of the body or occasionally during a particular technique or sort of patient. Most of those procedures involve the removal of some parts of the bones by machining processes.

This huge number of bone machining procedures performed should mean that extensive sensitivity research on the machining of bones is additionally conducted in tandem. However, that's not the case, a minimum of not from the view of machining itself as a part of manufacturing processes. Literature providing analysis of bone machining is extremely lacking. This example may be an equivalent to things generally machining (material removal process of a standard workpiece, for instance, metals), where the theoretical and analytical study of the machining process is lagging behind its practice or implementation. Our present research aims to contribute by viewing bone machining as a cutting or machining process with bone because of the workpiece. The machining process enables some marks which may effect on the machined workpiece. The evidence is on the surface, which is in direct contact with the cutter. Thus, one must concentrate on the machined surface, ensuring that the effect is minimum/less invasive. Also, knowing the hazard of bone necrosis to machining if the cutting temperature reaches 47^{o}C for over 1 min. There's a maximum allowable limit for temperature.

The machining responses should be taken under consideration to form sure that the machining process is conducted carefully. Still some of prominent researcher made an attempt on analysis of drilling in bone, as performed in orthopedic surgery, has a much more limited history. Eechtol et al., (1959) presented a set of guidelines for drilling in bone and for the manufacture of drill points. More recently, Sneath, (1967) reported the results of a similar study which produced recommendations for drill point configuration which are opposed to those of Bechtol et al. (1959), Matthews and Hirsch (1972), measured the temperature changes in bone during in vitro drilling. It was established the temperature distribution around a hole related to drill rotational speed. Jacobs, (1973) described the interrelationships between cutting forces, osteonal orientation and cutting tool geometry for single edge tools. The information used based on complete evaluation of the bone drilling process. More recently, the experimental and mechanistic modelling work of James et al., 2012 has been instrumental in shedding light on the cutting forces encountered during the machining of bovine cortical bone. While these studies reviled that the aided bone surgeries up to date, for the most part these were all macro-scale machining studies that were insensitive to microstructural variations in the bone. Furthermore, machining researchers have not paid much attention to the bone microstructure while interpreting their results. Some authors made an attempt on the cortical bovine bone is primarily made up of two load-carrying components viz., harversian bone and plexiform bone, both of which have distinctly different microstructure and properties. Manilay et al., 2013 studied the effects of these individual components on the machining responses of interest may not be isolated. From the extensive literature, our research work focus on the consequences of three machining conditions, that is, cutting speed, feed rate, and depth of cut, to machining time and surface roughness (a part of surface integrity) resulted from the machining process where it was performed to work out the significance of every input to output with provide magnitude relation between the outputs as a function of the input.

2.0 METHODOLOGY

The research work is characterized as per the Bovine bone and related cutting tools respectively with a motive to promote the benchmark assessing concept.

2.1 Materials Used

The work piece used was the femur of adult bovines (Figure 1) (age range of about 24–30 months), for its may be in resemblance to human's femur in structure and mechanical properties.

2.2 Preparation of Work Piece

The bovine bone is collected from the local slaughter market. The preparation of the workpiece (Figure 1-2) is performed shortly. Further removal of the tissue remains, and meats attached to the bone has to be removed before its dried up. The bone was washed as per standard procedure i.e., cleaned and preserved in saline water to maintain the hydration and to maintain the properties of the fresh bone. Due to the shape and tissue structure of the femur, only the central compact section is used for further processing.

Figure 1: Sample of femur bovine bone.

Figure 2: cutting of central compact section of the femur bone.

2.3 Experiential Equipment

Followings are the precious equipment's used for the present research work as mentioned below:

Figure 3: Cd6240x1500mm precision horizontal turning lathe.

Figure 4: Automatic power CNC milling machine (XKN714).

Figure 5: Leica microsystems transmitted light microscope binocular.

Figure 6: Ametek Taylor Hobson CCI MP-L.

2.3.1 CD6240X1500MM Precision Horizontal Turning Lathe Machine (Figure 3)

Present research dealt with Lathes are 2-axis machines. A lathe may be a particular machine used for shaping material like metal or wood by rotating it and using other tools to shape the fabric. Conversely, when using a horizontal lathe, the machinist works the metal in a side-to-side fashion. Turning is usually defined for cylindrical workpieces. Likewise, other materials for the present Bovine bone made similarly to execute the said task.

2.3.2 Automatic Power CNC Milling Machine (Figure 4)

CNC milling may be a certain sort of CNC machining. Controlling the machine is that the primary functions of a CNC. It includes the conversion of part program instruction into machine motions. This conversion maybe performed through a computer interface and a servo system. Milling is a process that is quite similar to drilling or cutting, and milling can perform these processes for a variety of production needs. CNC mills are often grouped by the number of axes on which they will operate. Each axis is labeled using a specific letter. However, the present research work made a novelty by using an end milling cutter to sizing the Bovine bone as per desired material removal rate.

2.3.3 Microsystems Transmitted Light Microscope Binocular (Figure 5)

The Leica DM750M is that the ideal microscope used in our research work for biomedical and Industrial appliances and some Material Science course. Its versatile stage and reflected light system add the combination to deliver high-quality images of the foremost demanding specimens. The mechanical stage is often used for both transmitted and reflected light. It can be equipped with various specimen holders to accommodate mounted specimens of different diameters. The unique Reflected light LED illuminator provides bright field, polarized light, and oblique illumination. This allows to work with many different specimens with the same microscope configuration. For the present research work its dealt with surface integrity at all the levels of the work, namely, turning, drilling and milling respectively to determine the twisting and ploughing effect as depicted in Figure 18-20.

2.3.4 Surface Roughness (Figure 6)

For our present research work Taylor Hobson CCI MP-L provisions modern CCI interferometer technology. With a 1024 x 1024-pixel array, it can provide nanometer resolution and an outsized FOV. It utilizes closed-loop diazoles Z-axis scanner to supply a 500-micron vertical range. CCI MP-L also offers the upgradability to CCI MP Functionality. As it was resulted with tangible in analysis the morphology of the bone.

2.4 Tools Used

8mm Index able Carbide Tipped Lathe Turning Tool, Dormer A108 HSS 8.5mm Jobber Drill Bit, 117 mm Plain Shank, Roughing End Mill 12mm Diameter 4 Flute AlTiN Coated Micro-grain Carbide 45HRC

Figure 7: 8mm index able carbide tipped lathe turning tool.

Figure 8: Dormer A108 HSS 8.5mm Jobber drill bit, 117 mm plain shank.

Figure 9: End mill 12mm diameter 4 Flute AlTiN coated micro-grain carbide 45HRC.

2.5 Machining Procedure

For the present research work, standard procedure was used based on recent developments in the biomedical applications. Cd6240x1500mm Precision Horizontal Turning Lathe Machine was used for the turning process. 8mm Indexable Carbide Tipped Lathe Turning Tools were selected for the investigation as the cutting tool. For Drilling and Milling, the Automatic Power CNC Milling Machine (XKN714) from BNK Engineering was used. An automated jig was established in order to hold the bone specimens during the turning experiment and to prevent the cracking of bone due to the chuck clamping force on the CNC lathe machine. The bone specimen preparation and tool setting were adjusted to ensure that machining is performed on the cortical part of the bone, at least partially. The machining parameters varied were cutting speed, depth of cut, and feed. The bone machining was performed dry, without any cutting fluid. Although it is not very common to perform bone machining procedures without irrigation (using water or saline solution as part of standard procedure), the dry machining had to be performed because observation on the types of chips generated by the machining process was also intended. It is found that during preliminary experimental runs using irrigation, the chips tangled and stuck to each other, likely because the chips were very fine in nature.

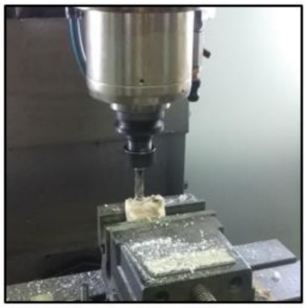


Figure 10: Milling


Figure 11: Drilling


Figure 12: Turning


Figure 13: Drilling Work piece


Figure 14: Turning Work piece

2.6 Preparation for Analysis of Surface Morphology

The workpiece was tailored as per the specimen for the optical microscope and CCI MP-L. it was precise to a particular machining part of the bone where machining has been performed. It may clearly observe some small cracks about the size of 2µm and various impacts on surface morphology due to the machining process that to performed recently on the femur bone. Figure 18 - 20 observed at a magnification of 10*/0.24 (Leica optical microscope). Figure 21-23 were observed at Ametek Taylor Hobson CCI MP-L.

3.0 RESULTS AND DISCUSSION

After performing the three machining processes with various parameters, the samples were inspected by Microsystems Transmitted Light Microscope Binocular as well as by Ametek Taylor Hobson CCI MP-L microphotographs of their impact on the surface being prepared as shown in Figure 18-23.

As the machining parameters experience exponential increase in case of turning process (Table 1) on the spindle speed, feed rate and depth of cut at a uniform manner with increased in percentage of 100-50%, 20-16.66% and 100-50% respectively which results in reduction of machining time from 14.98 to 18.75% (Table 4). It may be seen that the impact has deliberated on the turning of Bovine bone at a spindle speed of 30rpm, feed rate of 0.6mm/min and depth of cut of 300mm, (Case III of Table 1) the workpiece experience cracks on the turning sample (as shown in Case III of Figure 18) which leads in breakage of the bone structure which in turn lead to failure of Bovine bone. Hence resulting a surface roughness of 2.31Ra from Ametek Taylor

Hobson CCI MP-L readings which are analyzed as shown in Table 7. 3d mapping of the surface morphology of the turning workpiece is depicted in Figure 21.

In the case of the drilling process, the spindle speed, feed rate and depth of cut is increased at a uniform rate of 50rpm, 5mm/min, and 1mm respectively from Case I to Case III of Table 2. It can be seen that the effect on machining time due to the increase in these parameters has been effective in reducing from 13.81sec to 05.30sec. Percentile increment of spindle speed, feed rate and depth of cut maybe clearly shown in the Table 5. It is clearly seen that the surface material is pushed to the sides of the drill, as well as the formation of wear debris expelled to the edge of the impact on the bone (Figure 19). The debris resembles the twisting effect of bone fibers along with the direction of the drill which results in surface roughness of 3.93Ra (Table 7). 3d mapping of the surface morphology of the drilling workpiece is shown in Figure 22.

Similarly, for the milling process, the reduction of machining time from 25.45 to 17.23 secs can be achieved by the incrementation of spindle speed, feed rate and depth of cut at 50 rpm, 50mm/min and 0.05mm respectively. Percentile increment of spindle speed, feed rate and depth of cut may be seen clearly on Table 6. The surface material is pushed to the sides of the mill, as well as the formation of wear debris expelled to the edge of the impact on the bone. The debris resembles the ploughing effect of the bone surface along with the direction of the mill (Figure 20). Resulting a surface roughness of 1.24Ra from Ametek Taylor Hobson CCI MP-L readings (Table 7), making less impact on the surface morphology (Figure 23) leading it to be the better option of the two processes, turning and drilling process.

Table 1: Data collection table for turning process with HSS lathe cutting tool on lathe machine.

Spindle Speed (rpm)	**Feed rate (mm/min)**	**Depth of cut (mm)**	**Machining time (sec)**
10	0.2	250	11.35
20	0.4	300	09.65
30	0.6	350	07.84

Table 2: Data collection table for drilling process with 8.5mmdiameter drill bit on CNC machine.

Speed (rpm)	**Feed rate (mm/min)**	**Depth of cut (mm)**	**Machining time (sec)**
750	55	2	09.38
800	60	3	07.84
850	65	4	05.30

Table 3: Data collection table for milling process with 12mm diameter end mill on CNC machine.

Speed (rpm)	**Feed rate (mm/min)**	**Depth of cut (mm)**	**Machining time (sec)**
800	250	0.25	25.45
850	300	0.20	23.56
900	350	0.15	19.65
950	400	0.10	17.23

Table 4: Finding out the percentage of different parameters in Table 1.

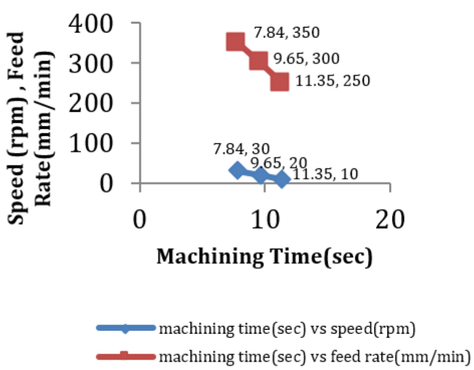
Cases	% Increase in Speed	% Increase in Feed rate	% Increase in Depth of cut	% Decrease in Machining time
Case I	100	20	100	14.98
Case II	50	16.66	50	18.75

Table 5: Finding out the percentage of different parameters in Table 2.

Cases	% Increase in Speed	% Increase in Feed	% Increase in Depth of cut	% Decrease in Machining time
Case I	7.14	10	100	32.07
Case II	6.66	9.09	50	19.64
Case III	6.25	8.33	33.33	32.39

Table 6: Finding out the percentage of different parameters in Table 3.

Cases	% Increase in Speed	% Increase in Feed	% Decrease in Depth of cut	% Decrease in Machining time
Case I	6.25	20	99.8	7.4
Case II	5.88	16.66	99.85	16.59
Case III	5.55	14.28	99.9	12.31



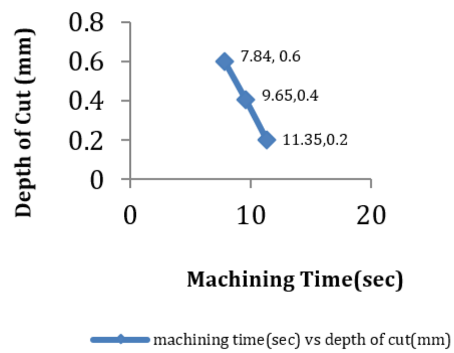


Figure 15: Comparison of speed, feed rate, and depth of cut w.r.t machining time for turning process.

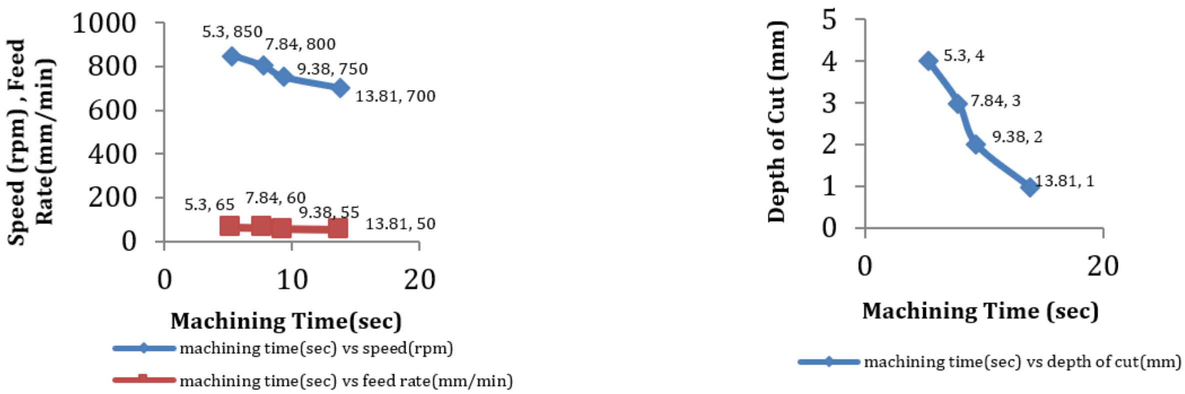


Figure 16: Comparison of speed, feed rate, and depth of cut w.r.t machining time for vertical drilling process.

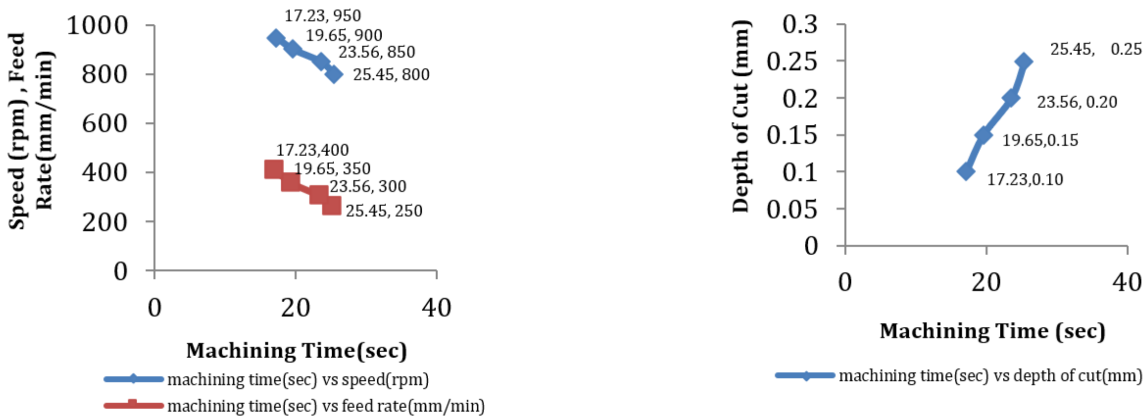


Figure 17: Comparison of speed, feed rate, and depth of cut w.r.t machining time for horizontal milling process.

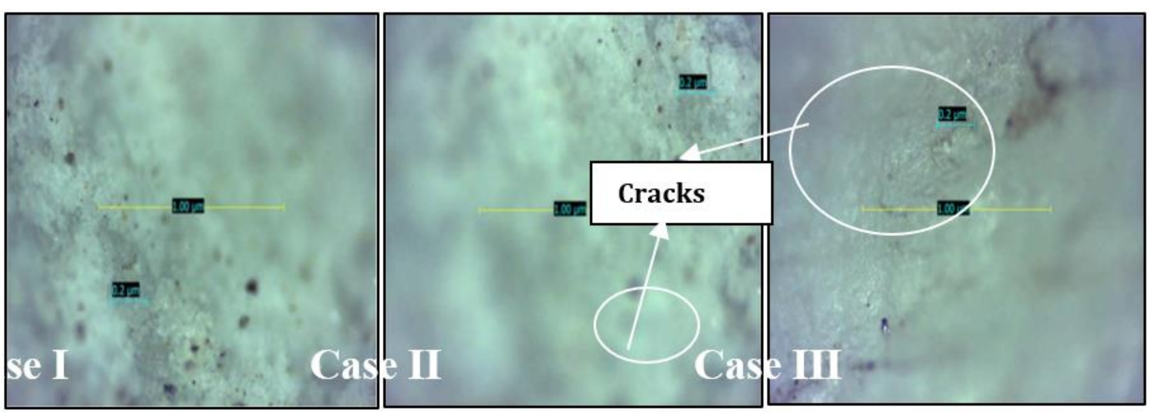


Figure 18: Surface integrity at turning work piece.

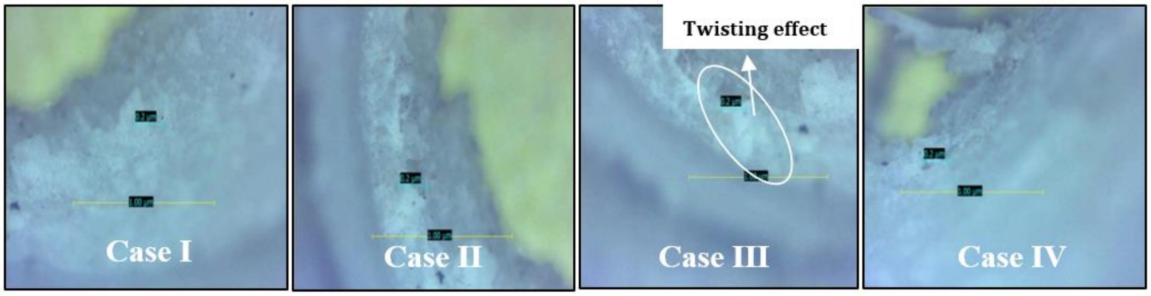


Figure 19: Surface integrity at drilling work piece.

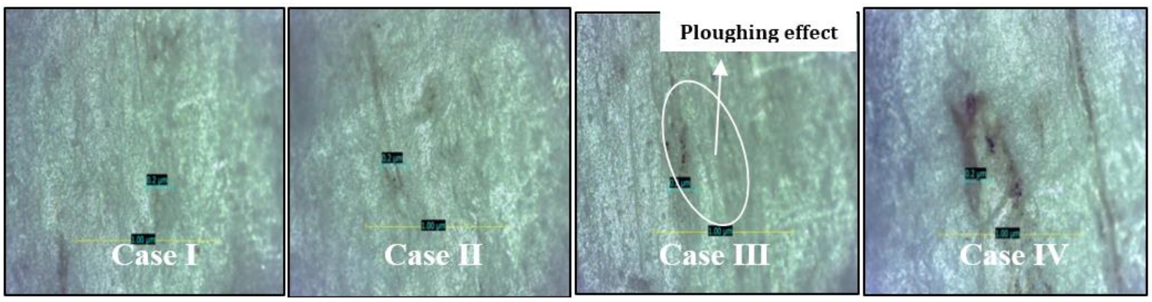


Figure 20: Surface integrity at milling work piece.

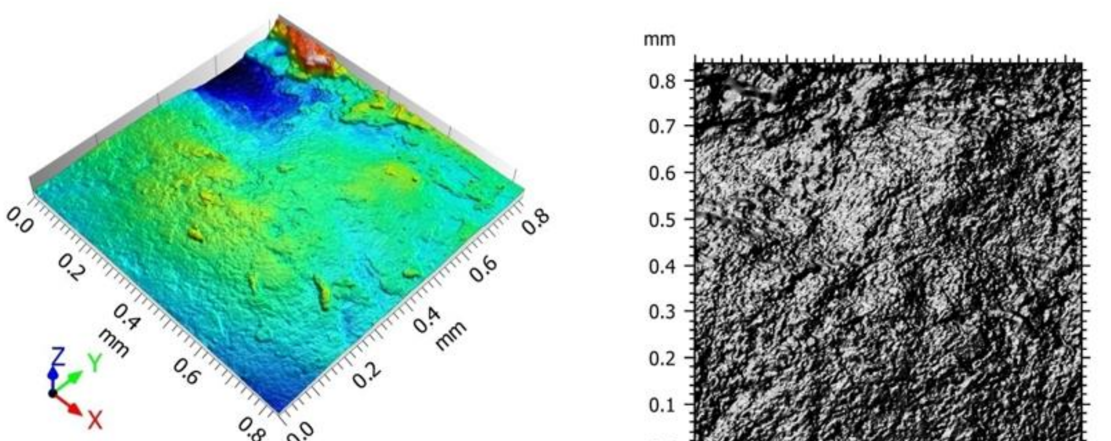


Figure 21: Surface morphology of turning on bone.

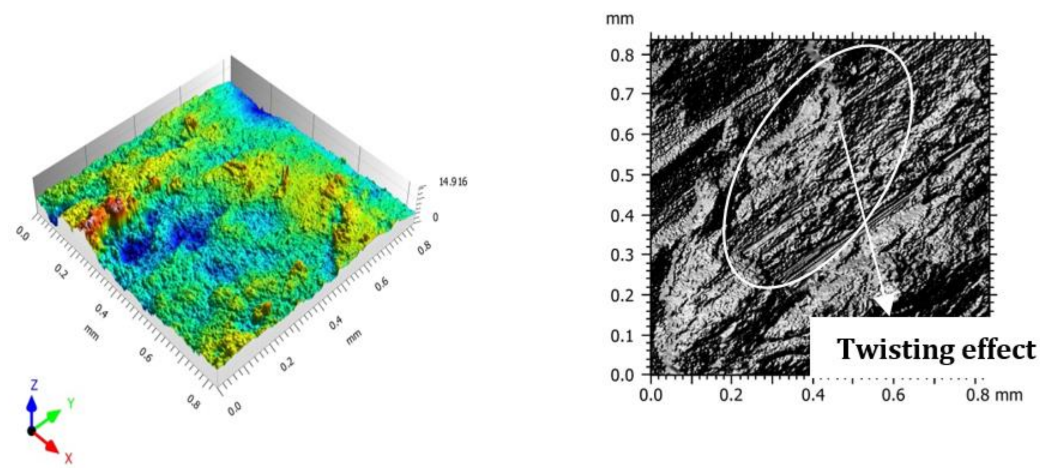


Figure 22: Surface morphology of drilling on bone.

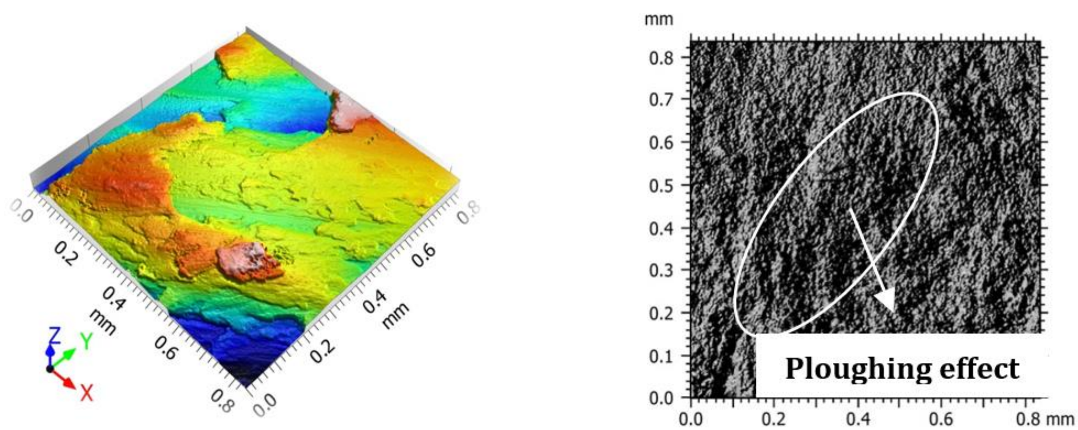


Figure 23: Surface morphology of milling work piece.

Table 7: Data collection table for surface morphology.

Type of machining process	**Surface roughness (Ra)**
Turning	2.31
Milling	1.24
Drilling	3.93

4.0 CONCLUSIONS

Following are the major conclusion drawn with the machining of Bovine bone as workpiece in turning, drilling and milling process respectively.It was found that with the increase in the speed from 800 to 950rpm, feed Rate of 250-400mm/min and decrease of Depth of Cut in 0.25-0.10mm there is a significant decrease in the machining time of Horizontal Milling process from 25.45 to 17.23 seconds.

And with the increase in the speed from 700 to 850rpm, feed rate of 50 to 65mm/min and increase of Depth of Cut in 1-4mm there is a significant decrease in the machining time of vertical Drilling process from 13.81 to 5.30 seconds. Similarly, it was found that with the increase in the speed from 10 to 20rpm, feed rate of 25-to 35mm/min and increase of Depth of Cut in 0.2-0.6mm there is a significant decrease in the machining time of turning process from 11.81 to 7.84 seconds. From the through investigations, it was also found that the Milling process makes less impact on the surface morphology leading it to be the better option compared to the two processes i.e. turning and drilling.

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