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Investigation of the Effects on Screw Thread of Infeed Angle during External Threading

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ABSTRACT

This paper presents the effects of the infeed angles in terms of the surface analysis and cutting force components on thread quality in the external threading operations. Threading operations were carried out on a CNC lathe by single-point cutting tools for 0º, 14.5º, 15º, 27.5º and 30º infeed angles at the constant cutting speed of 100 m/min. The main cutting force and the radial force were determined as significant force components in terms of energy consumption in threading processes. It was also determined that the microhardness increased toward the thread root from the thread crest throughout the flanks. According to experimental results and the surface analysis, it was found that the optimum infeed angle was 30º in external threading.

Keywords: *External threading, infeed angles, cutting forces, surface analysis.*

1. INTRODUCTION

Threading is one of the most common of manufacturing process. Threads are mass-produced by using two basic processes, forming and cutting [1]. Threads produced by forming are stronger because of the strain hardening occur during plastic deformation than threads produced by cutting, although forming can not achieve the high accuracy and precision required in many applications [2]. Threads made of brittle materials also cannot be produced by forming. In addition, external threads can be cut with a die and internal threads can be cut with a tap. But for some diameters, no die or tap is available. In such cases, threads can be produced by cutting process on a lathe [3]. Threads may be cut by using either a single or multi-point cutting process. In contrast to the traditional forming processes, the threads are formed by a single-point tool on a lathe [4]. On the other hand, the largest numbers of threads for general use are made by rolling. Both external and internal threads can be made by rolling. But the material must be ductile because this is less flexible process than thread cutting. It is restricted to simple parts and standardized. A roll tape requires a tighter size control of the pre-tapped hole than cut tap because oversize roll tap will create an error in both the minor and major diameters in the threaded part. As mentioned above, large numbers of threads are still manufactured by cutting process [5, 6].

In threading processes, the cutter has three cutting edges, i.e., one is the noise radius and the other two are side cutting edges. When the cutting edges cut a screw, each of the cutting edges produces one chip simultaneously. Then the chips resulting from those cutting edges interfere with further cutting, and the specific cutting forces become larger than those in orthogonal cutting. The chips following in different directions collide with each order, which affects the forces acting on the shearing area or on rake faces. Here, this phenomenon is called “interference of chips”. There are few detailed papers on the cutting force from the standpoint of chip interference [7]. During the threading via cutting process, there are various kinds of fluctuations (high-pressure cutting, vibration, chatter, built-up edge, etc.) and these are always accompanied with non-linearity. The fluctuations changes depending on tool geometries and cutting parameters and cause can be chipping, tool wear and/or fracture, undesirable cutting forces. These formations result in more energy

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consumption, reduction in tool life and poor surface roughness. Therefore, the cutting forces in terms of energy consumption should be considered when selecting the cutting parameters during machining [8, 9]. In threading operations, the friction between cutting tool and workpiece increase depending on the cutting with either sides of cutting tool, thus is an increase in cutting forces. Generally, the V-shaped type of flank wear on the cutting tool lead to the increase in the cutting forces. In addition, the V-shape type of flank wear, concentrated along the tool nose, alteration in edge geometry, loss of compressive strength, and thermal cracking occur during threading [10]. On the other hand, machining causes three important effects in the surface of the machined parts by means of microstructural changes on the materials: residual stresses, surface hardening (or rarely, softening), and surface roughness. The effects of these factors on the fatigue of parts are widely investigated and published. Thus, the effects of machining on these phenomena will also determine their effects on fatigue performance of the workpiece [11-14]. Hardening due to deformation (increase in dislocation density) and quenching (phase change) are different in terms of the material microstructure; however, this difference could not be distinguished clearly by mechanical means, specifically using the microhardness test [15].

Machining fine screw threads requires the optimization of the cutting conditions for minimum tool wear, and thereby minimum energy costs. Cutting conditions supplying maximum tool life may not supply threaded part geometrical precision. Therefore, screw threads are still manufactured by using various machining techniques suggested by the researchers and cutting tool suppliers for the improvement of productivity. One of these techniques is altering infeed angles during machining. Many infeed angles can be used in the threading but many of the CNC operators do not aware of the effects of infeed angles in the threading operation. This paper presents the effects of the infeed angles on screw thread by means of the surface analysis and cutting force components in the external threading.

2. EXPERIMENTAL CONDITIONS AND PROCEDURE

2.1. Experimental Setup

The machining experiments were performed by single point turning of AISI 1050 steel specimens in cylindrical form on a Johnford TC35 CNC turning centre with a variable spindle speed of up to 3500 rpm and a power rating of 10 kW. The thread size is dimension of M36x2 mm. Coolant was not used during the threading operations. Threading operations were performed on a CNC turning centre using the G76 threading cycle according to the Fanuc control system. The G76 multiple repetitive threading cycle provides a complete threading operation with 2 output blocks of information. The controller interprets the data in these 2 blocks and generates the multiple passes required to cut an entire thread. Different infeed angles can be used by means of G76 in threading operations, such as 0º, 14.5º, 15º, 27.5º, and 30º in this cycle [16]. Cutting force components were measured with a Kistler 9257A three component piezoelectric dynamometer and associated 5019 B charge amplifiers connected to PC employing Kistler Dynoware force measurement software. Analysis of thread surface was done in the two sections as taking surface images and microhardness measuring. Surface images were obtained by tool microscope (Mitutoyo-TM) from thread flank and thread root after threading operation. Surface microhardness measurements were carried out by using a Vickers indentor attached to a Shimadzu Microhardness Tester. These measurements were performed under a load of 10 N and 20 μm dept incrementally in step of 0.3 mm distance from crest to root at flank surface of the threaded specimen.

2.2. Cutting Tool and Cutting Parameters

The cutting tool was a commercial product available from Iscar, consisting of a tool holder and indexable inserts suited to ISO 5608 and ISO 1832, respectively. The product number of the tool holder was SER 2525 M16. Each insert was clamped on a standard 25 mm shank tool holder designated to provide a 10° clearance angle during threading. The coated carbide inserts were 16ERM AG 60 IC 908. Iscar Grade IC908 was a submicron PVD TiAlN coated grade. It was suitable for threading at low-to-medium cutting speeds. The cutting tool was appropriate for partial profile in metric threading operations and a new insert was used for each experiment. The cutting speed was held constant at 100 m/min recommended by the cutting tool supplier and thread pitch was chosen as 2 mm in the experiments. The first and last pass depths must be determined by the user when using the G76 threading cycle. The amounts of these passes were also chosen according to the recommendations of the cutting tool suppliers. These values were 0.4 mm for the first pass and 0.1 mm for the last pass or finishing pass and the thread profile was obtained with 9 passes. The other amounts of passes except from the first and the last passes were fixed by cycle depending on the first and the last passes.

2.3. Infeed Angle Methods

Three different types of infeed method named, radial, flank and incremental is used in the external threading. In practice, the selection of infeed method is determined according to the machine types, workpiece material, insert geometry and thread pitch [17]. Different angles between 0º and 30º must be used to provide an accurate thread profile in metric threading by the infeed method. Radial infeed method is the most common for producing threads. Since the tool is fed radially (perpendicular to the workpiece centreline), metal is removed from both sides of thread flanks, resulting in a V-shaped chip (Figure 1a). This form of chip is difficult to break, and so chip flow can be a problem. There is a risk of vibration for coarse pitches. In addition, because both sides of the insert nose are subjected to high heat and pressure, tool life will generally be shorter with this method than with other infeed methods. Tool wear is more even on both sides of the insert and the method is more suitable for fine pitches and work-hardening materials[17].

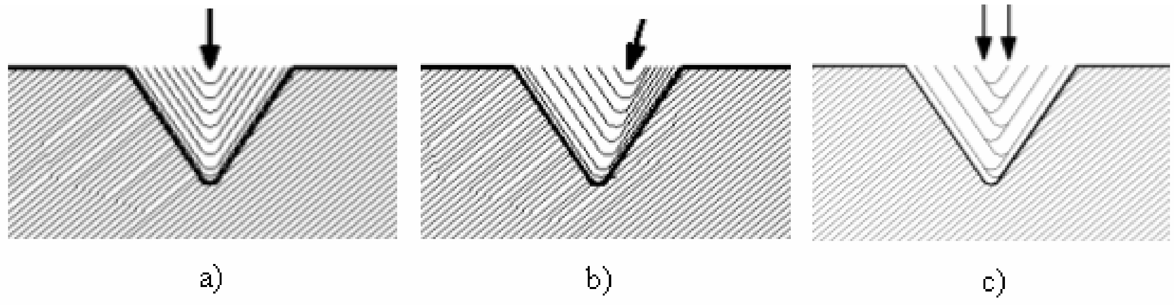

Figure 1. Infeed methods; a- Radial, b- Flank, c- Incremental [19].

The cutting edge is protected from chipping because both sides have infeed angles between 0º and 30º. The trailing edge of the insert may touch rather than the cutting edge, which can cause chipping at 30º infeed angle. In the 30º infeed method direction is paralel to one of the thread flanks. The shape of the chip is similar to what is produced in conventional turning. Compared to radial infeed, the chip here is easier to form and guide away from the cutting edge, providing better heat dissipation. However, with this infeed the trailing edge of the insert touches along the flank instead of cutting (Figure 1b). This may cause poor surface finish and chatter. The modified flank method is an advantageous method for modern thread turning and CNC lathes are programmed to have this method in cycles. This method is similar to flank infeed except that the infeed angle is less than the 30º angle of the thread. Chip control is better, the process being more similar to ordinary turning and for using chip breaker threading inserts, type geometry C. This process preserves the advantages of the flank infeed method while eliminating the problems associated with the insert's trailing edge.

In incremental infeed (Figure 1c), the cutting insert feeds along both thread flanks and therefore it uses both flanks of the insert to form the thread. This method may provide longer tool life because both sides of the insert nose are used effectively. However, this method also can result in chip flow problems that can affect surface finish and tool life. This method is usually used for very large pitches and thread forms such as Acme and Trapeze. Also, incremental infeed requires more complicated programming, and is not available on all lathes [17].

3. RESULTS AND DISCUSSION

3.1. Evaluation of Cutting Force Components

Threading inserts exposure to more stress than a typical turning insert as a result of the high cutting force and more narrow concentration of force. Therefore, the selection of infeed method has a significant impact on the effectiveness of the threading operation. In this section, it has been evaluated effects of infeed angles on cutting force components which are the main cutting force (F_c), radial force (F_r) and feed force (F_f) values. The assesments are made over the graphics generated according to cutting force values measured throughout cutting length.

The main cutting force (F_c) is more important than the other forces on cutting tool in orthogonal and oblique cutting [8]. As see in Figure 2, even though depth of cut of first passes is bigger than that of the other passes, F_c have obtained at the lowest values. This can be explained with friction which is decreased contact between cutting tool and workpiece due to cutting with one side of cutting tool. Although the depth of cuts between the second and eighth passes have the same value, the main cutting force values increased. It can be also seen from Figure 2 that the main cutting force decreased at eighth and ninth passes, which is finish operation. Though the depth of cut at the ninth pass is lower, F_c value is fourth order as numerical in this pass. These results can be attributed to the increase in chip cross-section depend on the cutting with both sides of insert [8]. The amount of the eighth pass is formed according to depth of thread (1.732mm) in G76 cycle. In spite of depth of cut at this pass was the lowest, F_c values for all infeed angles were bigger than those the first 3 passes. While the maximum main cutting force (882.62 N) was obtained with 15º infeed angle in seventh pass, the minimum value (51.05 N) was obtained with 0º infeed angle in first pass. The main cutting force increased a little with 14.5º in comparison to 0º but a considerable increase can be seen with 15º. Most of the uncut chip thickness was cut by the main cutting edge of the insert and the other part was removed by the trailing edge with 15º. One side of the insert was exposed to more friction between the cutting tool and the workpiece. Therefore, it has formed an unbalanced load distribution which caused an increase in F_c. A considerable decrease in the main cutting force was seen in the threading process with 27.5º. Most of the uncut chip thickness was cut by the main cutting edge and it caused gathering of loads on one side of the insert. Also, the total cutting area was removed by the trailing edge of the insert decreased [16], and thereby the amount of load affecting this side also decreased. Consequently, the main cutting force was decreased in comparison to 15º. The lowest main cutting force was obtained with 30º infeed angle, because the minimum total cutting area was occurred due to the cutting with one side of the insert at this infeed angle.

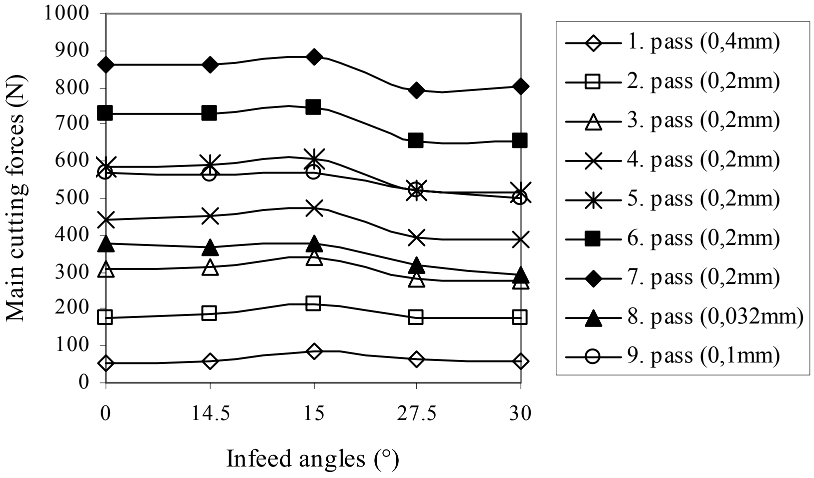

Figure 2. F_c variation depends on the infeed angles.

The feed force is secondary significant in terms of cutting power or energy consumption in orthogonal cutting processes. Approximately 1% of total power is used by the feed force [18]. According to experimental results, the F_f/F_c ratio was obtained as 0.18 at cutting process with 30º infeed angle where the feed force reached its biggest value. Hence, it can be inferred that the feed force cannot be considered in terms of cutting power. It is seen from Figure 3 that the feed force has not been important in comparison to orthogonal cutting processes. However, the main cutting edge and the trailing edge of the insert must be perform the cutting process simultaneously to produce V-shaped chip geometry in threading operations. In this process, loads affected both the trailing and main cutting edges in the feed direction in balance to each other. This balance was broken due to some reasons such as vibration, choice of cutting tool, and clamping mistakes [16]. It can be seen from Figure 3 that the feed force has a different tendency in all infeed angles in comparison to the main cutting force. While the maximum feed force was obtained with 30º at the seventh pass, the minimum value was obtained with 0º at the eighth pass. While the difference of feed force between 14.5º and 15º infeed angle was small, this difference increased after the 15º infeed angle. Most of the uncut chip thickness was removed by the main cutting edge and this caused gathering of the loads on this edge. The minimum total cutting area and one side cutting process with 30º caused the highest value of the feed force.

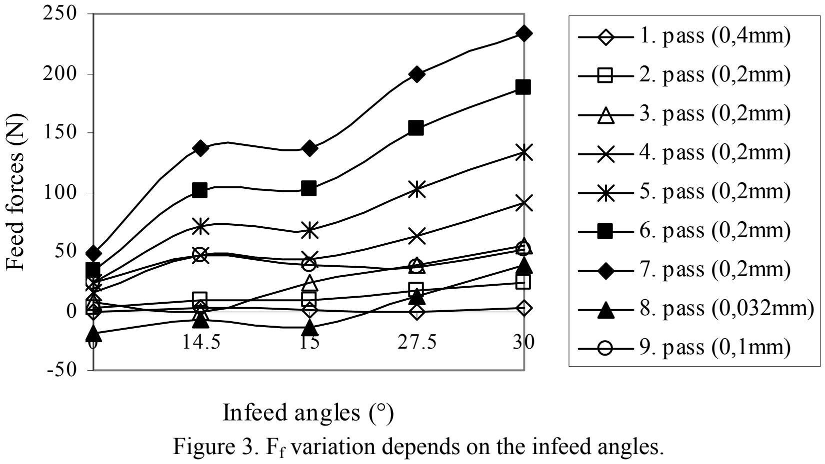

Figure 3. F_f variation depends on the infeed angles.

Radial force is about an average of 50% of feed force in orthogonal cutting process since there is no velocity in the radial direction. This is means that the effect of radial force on cutting power or energy consumption is insignificant [18]. According to experimental results, the F_r/F_c ratio was obtained as 0.46 with 15º infeed angle where the radial force reached its biggest value. Compared to with orthogonal cutting in terms of energy consumption [5,8], it is possible to say that the radial force is more important in machining operations such as threading and grooving. As seen from Figure 2 and Figure 4, the trend of the radial force with the main cutting force values for all infeed angles is similar. While the maximum radial force was obtained with 15º infeed angle at the seventh pass, the minimum value was obtained with 0º infeed angle at the first pass. F_r values increased a little with increasing from 0º to 14.5º of infeed angle whereas a considerable increase in the cutting with 15º (see in Figure 4). Most of the uncut chip thickness was removed by the main cutting edge of the insert and the other part was removed by the trailing edge with 15º and one side of the insert was exposed to more friction between the cutting tool and the workpiece. Thus an unbalanced load distribution occurred and caused an increase in the radial force. The lowest radial force values occurred in the cutting process with 30°. As explained in Ref. [16], this result can be attributed to the decrease in total cutting area and load amount depending on the cutting with the trailing edge of the insert.

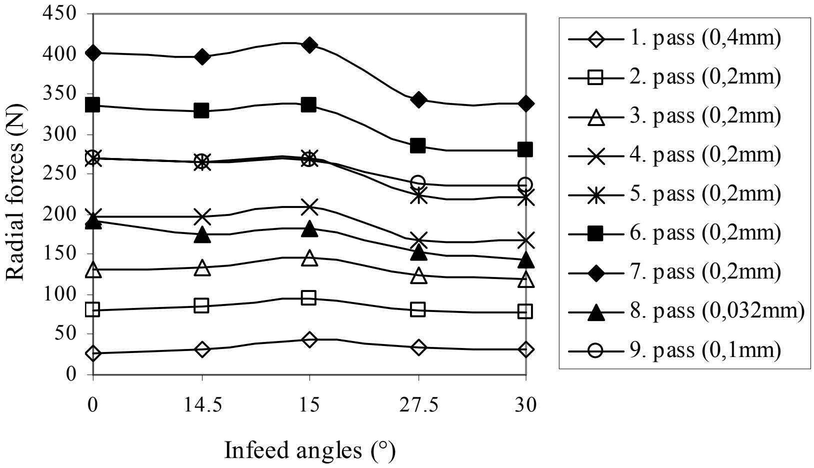

Figure 4. F_r variation depends on the infeed angles.

3.2. Analysis of the Thread Surface

Generally, the analysis of thread surface includes quantitatively characterizing the thread profiles, interrogating the thread surfaces and hardness measuring. The analysis of thread surface is related to thermal and mechanical effects of residual stresses and strain hardening as determined Ref. [19]. Therefore, the analysis of the thread surface has been performed surface images taken by optical microscope and hardness measuring in this study. The optical micrograph of the root, crest and flank of the threads for different infeed angles is given in Figure 5.

As seen in Figure 5, the feed marks and tears occurred at both the thread root and the thread flanks for some infeed angle (14.5°, 15° and 27.5°). This can be attributed to the increase in radial cutting force of the additional forces occurred with alteration in the tool nose and clearance surface as a result of the rubbing effect between the both sides [10]. In addition, the adhesion of chips on the thread crest can be attributed to the ploughing effect between the two contacting bodies (due to alteration in the trailing edge) as shown in Figure 5. According to mine experimental study obtained results have indicated in a good agreement compared to a previous study [10]. Ezugwu and Okeke are also point out that the increasing of radial force could be causes poor surface quality.

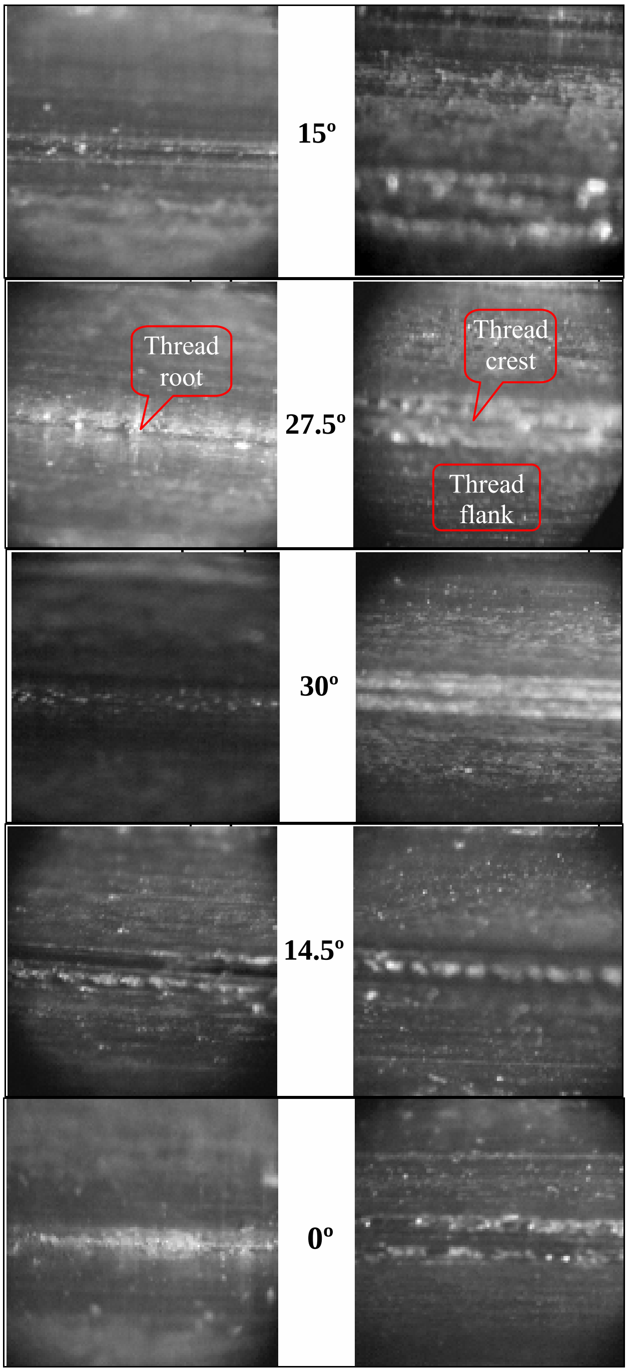

Figure 5. Microscope images of the thread surface obtained after machining (20X).

Threading operation involves a strain hardening of the material constituting the thread. This hardening due to deformation (increase in dislocation density) and quenching (phase change) are different in terms of the material microstructure [15]. The strain hardening is quantifiable by microhardness measurements [20]. Also, surface hardness becomes higher because the yield stress of the surface layer increases by the strain hardening which is depend on the intensity of the friction between the cutting tool and the work material [21]. For this reason, the microhardness measurements were performed on the thread flank in the depth of 20 µm from machined surface (see in Figure 6), where occured maximum residual stress according to Ref.[14]. The initial microhardness of the work material used in this study is 220 HV. Microhardness values measured from the flank surface after the threading operation is shown increase up to 295 HV in Figure 6. On the other hand, microhardness is illustrated tendency to increase from thread crest to thread root along the flank surface for all infeed angle. This increase can be explained by operating principle of the flank infeed method. In this process, tool-chip contact length increases with the radial feed of the cutting tool, thus cutting force increases [9]. Also, as mentioned in Ref.[10 and 14], a phase change may have occurred due to higher heat generation, therefore the surface layer of thread root may have been hardened. As well as, an increase in plastic deformation with increasing of total cutting area lead to increase of microhardness value toward thread root. It were occurred an increase in the hardness and the radial force values because of the pulling effect between both the cutting sides (see in Figure 4). The lowest microhardness was obtained after threading process with 30° infeed angle when the flank surface microhardness results is carefully observed.

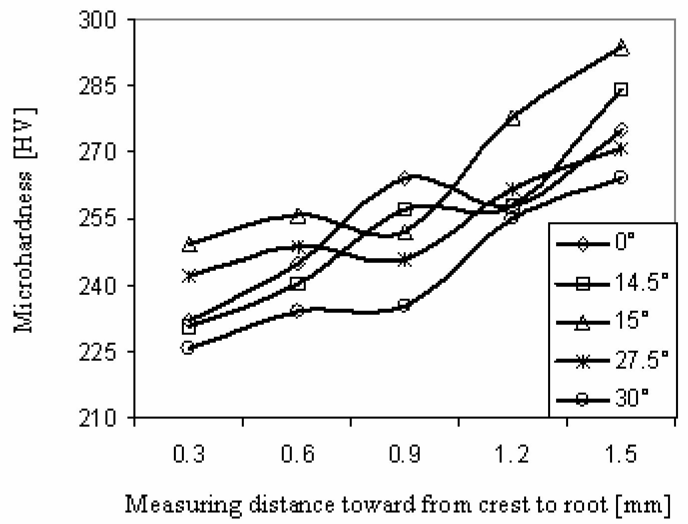

Figure 6. Microhardness values measured on the thread flank.

4. CONCLUSIONS

The results obtained from this study can be summarized as follows:

1. According to cutting forces results, the radial force is secondary significant after the main cutting force in terms of cutting power in threading operations.
2. Microhardness increased from thread crest to thread root along the flank surface because of phase change may be occurred due to higher heat generation and increase in pulling effect with increasing of total cutting area toward thread root.
3. While the feed marks and tears occurred at the thread root, surface damages such as feed marks, smearing and pits became on the thread flanks, especially for infeed angles of 14.5°, 15° and 27.5. This can be attributed to the increase in radial cutting force obtained with alteration in the tool nose and clearance surface as a result of the rubbing effect between the both cutting sides.

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