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MACHINABILITY PARAMETERS IN FINISH FACE MILLING OF LOW ALLOY Cr-Ni STEEL WITH THR K30 CARBIDE TOOL

PART II: SURFACE FINISH, MACHINED SURFACE TEXTURE, MINOR CUTTING EDGE AND NATURE OF CHIPS.

عوامل قابلية التشغيل فى التفريز الرأسى الدقيق لسبيكة صلب نيكل كروم باستعمال لقم كربيدية تى إتش ار كى ٣٠

الجزء الثانى : نعومة السطح ، تكوين السطح المشغل ، الحد القاطع الثانوى ، طبيعة الرايش

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ملخص : الجزء الثانى من هذا العمل يبحث نتائج التفريز الرأسى الدقيق فى صورة درجة نعومة السطح وتغيرات السطح المشغل لسبيكة صلب فى حالتها المصلدة . تم اقتراح ميكانيزم القطع الأمامى والخلفى ومن ثم تحديد درجة نعومة السطح . التفاصيل المرتبطة بكل من هندسية الحد القاطع ، التشوه المرن ، علامات القطع المنتقلة إلى السطح المشغل بالحد القاطع الرئيسى فى حالة التفريز الأمامى - كذلك عملية تنعيم السطح بواسطة عملية السحق بالحد القاطع الثانوى فى حالة التفريز الخلفى تم استعراضها ومناقشتها بالتفصيل .

وقد توصلت الدراسة إلى أن استعمال هذا النوع المتطور من اللقم الكربيدية قد أعطي درجة عالية جداً من التشطيب والبريق . بناءاً على هذه النتائج فإننا قد زودنا بمعلومات ضرورية تمكننا من اتخاذ قرار استبدال عملية التجليخ الرأسى بعملية التفريز الرأسى الدقيق .

ABSTRACT

The second contribution presents the results of finish face milling in which the performance of THR K30 reported in terms of surface roughness and machined surface alterations when a low alloy steel in its hardened conditions was milled. The assessment of surface finish and the mechanisms involved in particular front and back cutting were defined. Details are given corresponding to, the geometry of tool, elastic deformation and feed marks transfered to surface during front cutting. Also, in back cutting, the surface refining by burnishing process on the trailing end cutting edge was comprehensively explained. The effect of minor flank wear width on surface refining has been studied. Based on the findings, the THR K30 tool gave the least surface roughness value and the brightest surface.

The surface roughness values could be the determining factor and provide the necessary inforamtions in a decession to change from surface grinding to face milling.

1- INTRODUCTION

The final condition of the machined surface is controled by the chip-workpiece as well as the tool-workpiece interactions. Earlier reseach work was concerned with the machining of metals that led to the significant understanding of surface roughness characteristics [1-16]. Observations were made of built up edge, side flow, wear of tools and the orgin of surface roughness. Some other work were concerned with the machining of difficult to machine alloy steels to improve and enhance machined surface quality [17-24]. Using various coated tools and refractory cutting tool materials have been more used in order to improve tool wear and cutting capacity [25-31]. Recently, a number of papers [32-35] have been published in which the steels turning process with using the CBN tool has been suggested as a substitute for the grinding process. On the other hand, there are very few data available in the literature dealing with the milling process [36-39], which is widely used in the arearospace industry.

The purpose of this investigation is a continuation of these attempts to find if vertical spindle surface grinding can be replaced by face milling. In this study, the model of resulting surface in fine face milling is proposed. It was desired to establishing relationships between the minor flank wear of the THR K30 tool, cutting speed and feed and surface finish in finish face milling. It is then followed by the concept of burnishing action on the trailling end cutting edge to improve surface finish is basically investigated. Moreover observations of the burnished machined surface, minor cutting edge conditions were examined by SEM and EPMA.

2- EXPERIMENTAL CONDITIONS

Choice of tools, work materails, the cutter, the cutting conditions, contact condition and the cutting action were previously stated in the first paper.

3- EXPERIMENTAL PROCEDURE AND MEASUREMENTS

The surface roughness test specimen was sawed and removed from the bolster after every single pass and the roughness of each surface was determined. The specimen was placed on the surfcom 300B table and its position was fixed during measurements in which the diamond stylus was set at a position 16 mm away from the engagament edge in order to simulate the cutter centre line position during the cutting. The readings of roughness were taken at different positions along the surface and in the direction of feed motion. The centre line average height method, CLA for the assesment of surface texture was adopted.

The SEM was used to analyse the texture of the machined surface qualitatively. A single piece of 20x10x5 mm was cut 5 mm from the plane of the engagement of the workpiece where the steady state machining condition was established. In addition, chips and worn tip were also examineed on the SEM. The distribution of the metal over the minor flank area was determined using an EPMA.

4- EXPERIMENTAL RESULTS AND DISCUSSION

4.1- Model of Resulting Surface in Cutting Region

In face milling the pattern of surface irregularities is specified by two forms of cutting, i.e. (i) front cutting and (ii) back cutting. It is difficult to avoide back cutting because of elastic recovery of metal being cut and run out of spindle. Hence, all machined surfaces produced in this investigation are specified to the method in which the machined surface is influenced by back cutting action. Fig. (1) shows a model of resulting surface with sharpened and worn region of finish face milling. In this figure, a small volume element of cutting region, enabling relationships between main cutting edge in front cutting, trailling end cutting edge in back cutting and work material to be inferred from the tool geometry and work material property. When cutting with main cutting edge, Fig. (1a), all chips were generated with full depth of cut and the profile of cutting edge is transfered to the machined surface. However, the high vertical force Fz generated during cutting, the steels will cause a local elastic deformation in region near the cutting point as indicated by, Δ. It may be added that, the ridges corresponding to the geometry of tool, feed marks and irregularties on the minor flank transfered to surface during front cutting will be included in the elastic recovery depth as long as the roughness value is lower than the amount of elastic recovery,Δ .

Conversely, in back cutting, Fig. (1b), the elastic recovery value Δ, represents the actual depth of cut. In relation to the diagram, small chips formed at the trailing cutting edge, whilst, very thin chips were cut off or burnished by trailing end cutting edge. In deep, at this elastic recovery depth Δ, there is elastic deformation of the metal surface due to burnishing process on the trailing end cutting edge. But, on the trailing cutting edge as the depth is increased, the metal is plastically deformed and pushed up and eventually a small chip is formed, Fig. (1c).

Since the hard materials is characterize by the high ratio of hardness/modulus of elasticity, high stress at the tool-workpiece contact will cause appreciable amount of local elastic recovery [24]. The calculated value of hardness/modulus was of the order of 0.02 indicating that the material has an appreciable amount of elastic recovery of the order of 10 µm. This was also evident from the comparison of the measurements of the actual workpiece thickness left behind and of the theoretical workpiece thickness.

4.2- Surface Roughness

In the light of the model proposed and previous discussion, it is clear that the trailing end cutting edge was significantly involved in production the machined surface in both front and back cutting. Thus, there was a need to exame the effect of minor flank wear on the surface generated. The CLA values perpendicular to the machining marks and the magnitude of the associated minor flank wear are recorded and shown in Fig. (2a).

The trend is first shown a deterioration followed by an improvement and then finally deteriorating beyond the values initially recorded. It is believed that these three regions have some relations to those found during the investigation of wear versus cutting time as shown in Fig. (2b), in which an initial rapid wear (I) followed by almost uniform wear (II) and then final sharp increase in wear (III). Fig. (3) shows a reproductions of actual Talysurf records. By examining the results in Figs. (2) and (3), trend line can be extracted and the conclusion can be reached, that the surface finish can be affected considerably by minor flank wear during front and back cutting action. However, the surface roughness was minimum at minor flank wear value of about 150 µm where this value represents the optimum performance for the THR K30 tool.

a- Effect of Speed

The effect of cutting speed on the surface roughness using tools having an optimum minor flank wear value, i.e. 125 to 150 µm. and sharp one, in both front and back cutting is shown in Fig.(4a,b) respectivly. This figure also shown, a comparison between geometrically calculated surface roughness [16] and the actual surface roughness obtained by the THR K30 tools. In general, the increase of the speed reduces the surface roughness for both front and back cutting. However, better surface finish is achieved with worn tool compared with sharp tool in all tests conducted. Although the general trends observed are simillar, the actual surface roughness values are considerably higher than the geometrically calculated values at a cutting speed below 130 m/min in front cutting and below 90 m/min in back cutting. For the sake of comparison, at cutting speed of 110 m/min, the surface roughness achieved was of about 0.7 µm in front cutting whilst was of about 0.4 µm in back cutting. At the highest test speed of 176 m/min, the machined surface had the lowest roughness value of 0.2 µm in back cutting. To the other knowledge, it is the best finished surface roughness in fine face milling up to this time.This means that a better surface finish has been achieved in back cutting than in front cutting at the same speed, indicating to the agreement between the proposed model and actual roughness readings. This is ascribable to the burnishing process conducted by the trailling end cutting edge as explained by the model in Fig. (1c).

b- Effect of Feed

Fig. (5) shows the effect of feed on the surface roughness of both front and back cutting. A consistent and general trend was noted in the increasing of surface roughness values with increasing feeds in both front cutting, Fig. (5a) and back cutting, Fig. (5b), showing that front cutting produced higher surface roughness values than back cutting at the same feed per tooth. However surface roughness values were lower than the geometrically calculated values at feed per tooth between 0.1 to 0.15 mm/tooth. The surface roughness becomes higher than the geometrically calculated values when the feed was further increased beyond this finishing range. Decreasing the feed less than this range resulted in limited effect on surface finish. Since the length of sliding contact between the tool minor flank and machined surface increases with the decreasing of feed/tooth, then burnishing action in back cutting is also excepected to be increased. This indead the case as Fig. (5b) indicates.

During the run-in stage of the slightly worn tool, the surface temperature of the workpiece will increase beyond the calculated temperature of value of 800°C. Further increase in cutting speed and decrease in feed/tooth will produce a reduction in force component, because of an increase in temperature which in turn produces a condition of seizer developed between tool nose and machined workpiece surface [21]. It is believed that such conditions will produce a plastic deformation within surface, leads to a surface burnishing appearance having an extremely low surface roughness value of 0.2 µm at speed of 176 m/min and minor flank wear of 150 µm. Therefore , the assumbtions of the propodes burnishing model is valid and the burnishing action occured by the back cutting is fulfilled and surface finish generated are thus more improved.

4.3- Surface Examination

The electron scanning micrographs shown in Figs. (6a,b) were obtained from the surface for the same cutting condition when a sharpened and worn tool of TTM P30 were employed. While , Fig. (6c,d) shows the electron scanning micrographs of the machined surface produced by sharpened and worn THR K30 tool. From these figures, the machined surfaces consists of a number of common features such as well defined long straight (g) parallel to the cutting direction, microchips (mi) and microchip grooves (gm) which are present on all the surfaces. Fig. (6a), shows scratches and side flow on a feed groove and the presence of ragged long straight grooves (g) parallel to cutting direction. Fig. (6b), the surface consists of many more microchip grooves (gm), left by microchip (mi) with ill defined long straight groove and the step like featuress(s) show evidance of severe plastic deformation (p). For TTM P30 tool, the generation of built-up layers at the minor cutting face and the adhered particles are remarkable Fig. (7a) and confirmed through X-ray image for iron Fig. (7b). This results in the production of pressure welded particles to the surface or different type of scratches and finally an entirely different surface is generated. Therefore, the surface roughness measurements reflected these instabilities in terms of Ra values which increased.

However, for the sharpened THR K30 tool, the surfces in Fig. (6c) are charactrised by the presence of well defined long straight pronounced feed marks (fm). The surface generated by application of the worn THR K30 tool Fig. (6d). consists of microgrooves (gm) left by the microchip (mi). This figure also shows, tear marks have been swept away with no machining marks and scratches of the same type are observed for long distance. These scratches may be caused by the replication mechanism of the fine roughness existed on the minor flank area. Clearly, the worn THR K30 tool offered a high protection against adhesion by the workpiece material, Fig. (7c) and confirmed through X-ray image for iron Fig. (7d). This once again correlate well with production of smooth surface, Fig. (6d).

4.4- Surface Refining by Burnishing

The roughness on minor cutting edge of TTM tool tend to capture metal mechanically and lead to formation of a built up layers Fig. (7a,b). Hence we conclude that the roughness on the minor cutting edge is responsible for metal adhearing into the tool and subsequently breaking off leaving an anistropy degraded surface. These instabilities reflected itself in terms of increased the Ra values.

In contrast, the THR tool was found polished smooth by the machining, Fig. (7c,d). The resulting is a smooth surface which has a lower quantity for random components, the actual surface roughness is very close and lower than the geometrically calculated values. From the previous discussion, the surface roughness with THR K30 tools is considerably lower than with a TTM P30 tools. It was concluded in the first contribution of this work that, with the THR K30 tool the vertical force Fz at a constant cutting speed, is larger than that with the TTM P30 tool. Additionally, the force components especially the vertical force Fz were found continuously increase with an increase in minor flank wear. By comparing the surface roughness, machined surface examined and the vertical force Fz for both TTM and THR tools, a mechanism of improvement of machined surface by burnishing action [24,40] related to the high vertical force Fz, seems to exit with worn tool. This means that the increase in vertical force may be caused by burnishing the machining grooves, scratches and wear anistropy to the machined surface in both front and back cutting. It is clear now, that surface roughness and/or machined surface conditions has a strong correlation with vertical force Fz within an optimum minor flank wear value of 150 µm.

4.5- Nature of Chips

The structure of tested alloy chips produced at high speed of 176 m/min and feed of 0.1 mm/tooth using THR K30 worn tool reveals that segmented chips are formed. It composed of alternative seperate regions of almost equal width and the free surface of chips are characterized by a fine lamellar stracture, Fig. (8). The lamellae are separated by shear zone on a thin plane which is plastically deformed and heated to a higher temperature [34,35]. In addition, the chip segmentation was clear for all cutting conditions and lesser burned with light blue colour at high speed than at low speed. Since the high values of cutting force components associated with worn THR K30 tool lead to the formation of surface cracks [34], it is excepected that the chip segmentation caused by formation of cracks will release high restoring forces. Investigations puplished [34,41] indicate that the releasing of such high restoring forces induce a compressive residual stress state in the machined surface .

Although, the increase in cutting speeds using a THR K30 tool having a burnishing action on the minor cutting edge will produce a fine surface as a consequences of an increase of vertical force Fz. It was realized that minor cutting edge condition and its effect on surface quality is a testmony to the fact that the subject of surface finish could not be considered solely in terms of Ra values. This because the machined surfaces could be damaged metallurgically whilst still meeting the surface finish specifications. In this regard, this aspect will be considered in details in next work.

5- CONCLUSIONS

The surfaces of low alloy steel in its hardened conditions were face milled using the conventional sintred carbides of TTM P30 and their modified reduced cubic carbides of THR K30 to find if the surfce grinding operation can be replaced by face milling. The model of resulting surface in the cutting region with sharpened and worn tool in front and back cutting are proposed and shown schematically in Fig. (1). At the main cutting edge and especially the traillling end cutting edge where the final surfaces are generated, the following conclusion can be made.

1- When most chips are generated in front cutting, elastic deformation produced and machining groves remain on the machined surface without being removed by the minor flank face. On increasing the cutting speed from 110 to 176 m/min, the value of Ra decrease from 0.8 to 0.4 and from 0.65 to 0.3 μm for sharp and worn tool respectively.

2- In back cutting the machined surface roughness is improved by the effect of the decreasing of tool setting angle, δ as a result of increasing the worn traillling end cutting edge angle δΔ. On increasing the cutting speed from 110 to 176 m/min the value of Ra decrease from 0.45 to 0.3 and from 0.4 to 0.2 μm for sharp and worn tool respectively.

3- A better surface finish were achieved with worn tool in back cutting than in front cutting, indicating to the agreement between the proposed model and actual roughness readings. This was attributed to the burnishing action on the 10 μm elastic recovery depth conducted by the traillling end cutting edge as suggested by the model in Fig. (1c).

4- Surface roughness values were lower than the geometrically calculated values at lower feeds of 0.1 and 0.15 mm/tooth. This was due to that the sliding contact detween the minor flank and machined surface increase with the decreasing of the feed/tooth. So, the burnishing action on back cutting is also excepected to be increased and surface finish are thus more improved.

5- The worn THR K30 tool offered a high protection against adhesion by the workpiece material. this once again corelate well with the production of smooth surface. An optimum minor flank wear width of 150 μm was found at the high speed of 176 m/min.

6- The mechanism formation of the surface structure has been disscussed in terms of minor flank wear and cutting conditions. Chip segmentation were found for all cutting conditions.

7- With the modified compositions of THR K30 carbide inserts, it is possibl to face milling components to surface finish values of order 0.4 to 0.2 formerly the domain of grinding process. So, the vertical spindle sur grinding can be replaced by face milling.

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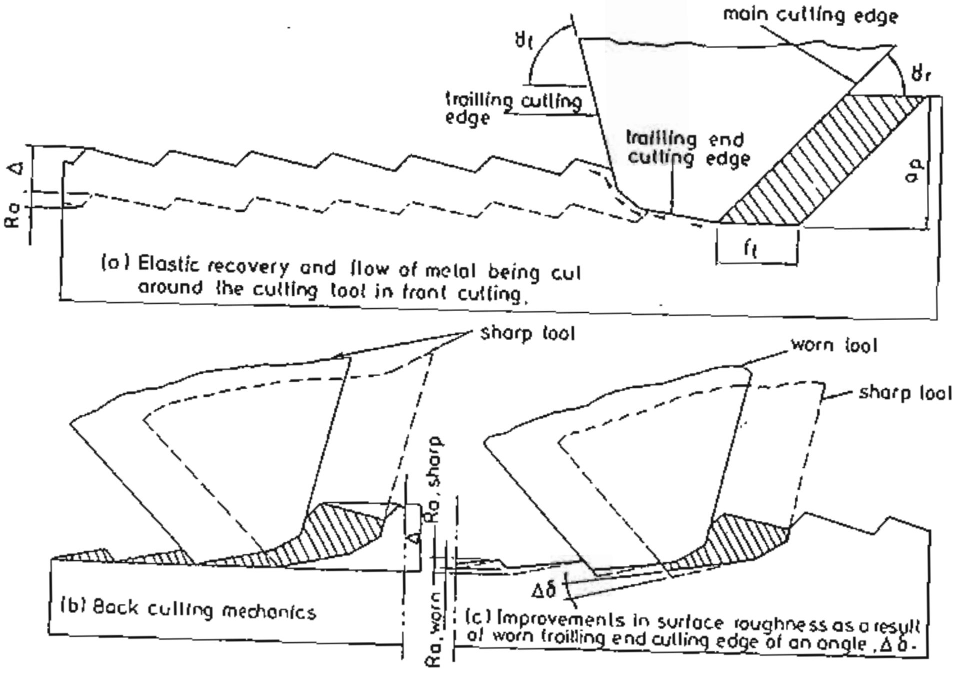


Fig.(1) Model of resulting surface in the cutting region.

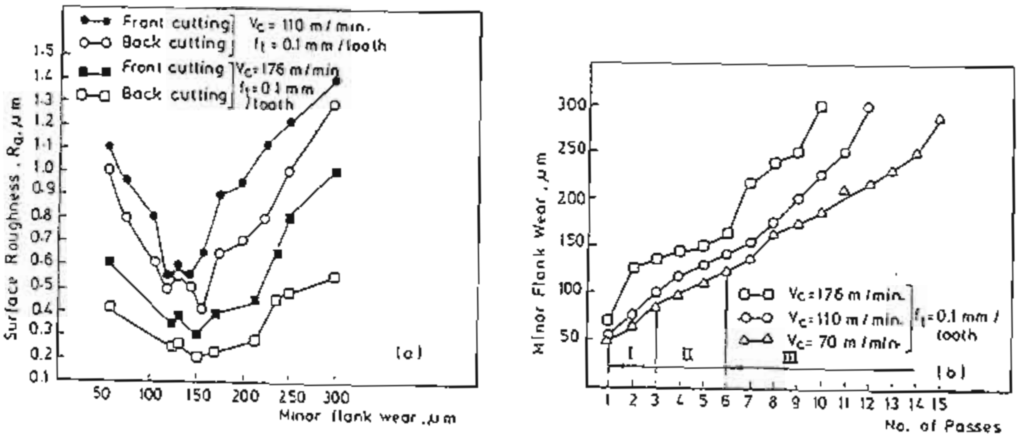


Fig.(2) a- Effect of minor of flank wear on surface generated.
b- Minor flank wear versus No. of passes.

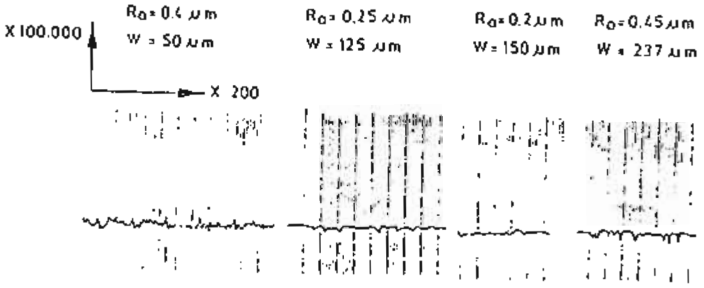


Fig.(3) Reproduction of actual Talysurf records when using different minor flank wear weadthes of THR tool at cutting speed 176 m/min. and feed 0.1 mm/tooth.

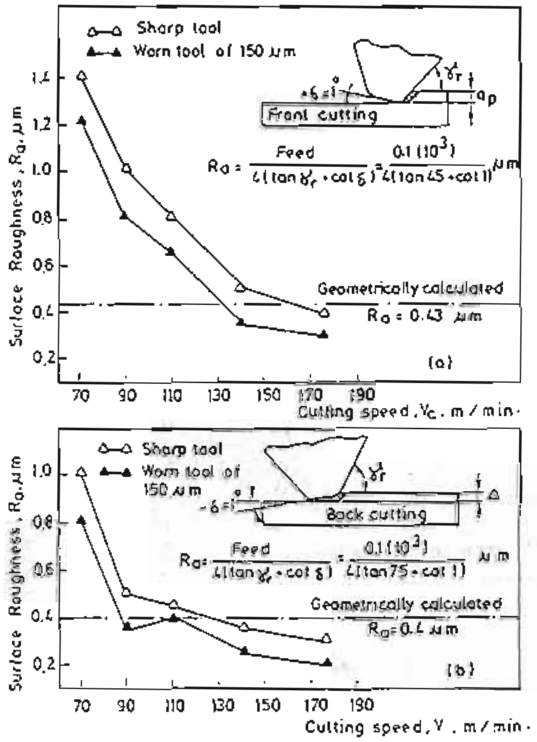


Fig.(4) Effect of cutting speed on the surface roughness.

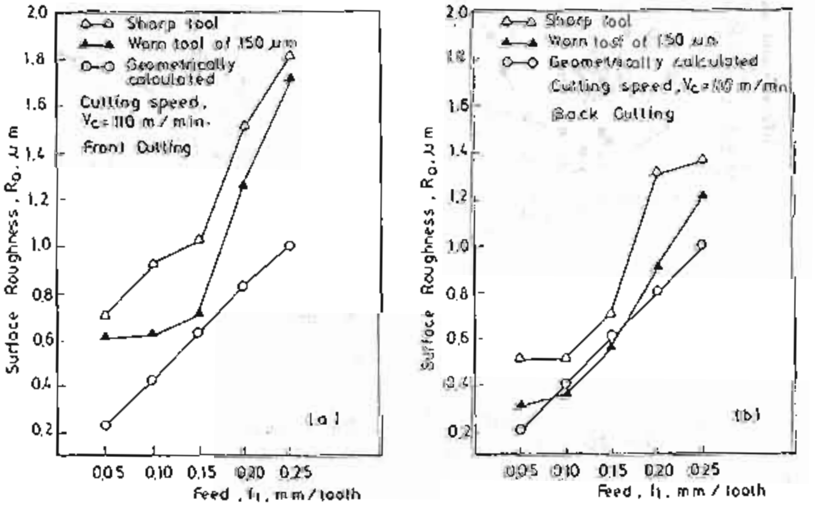
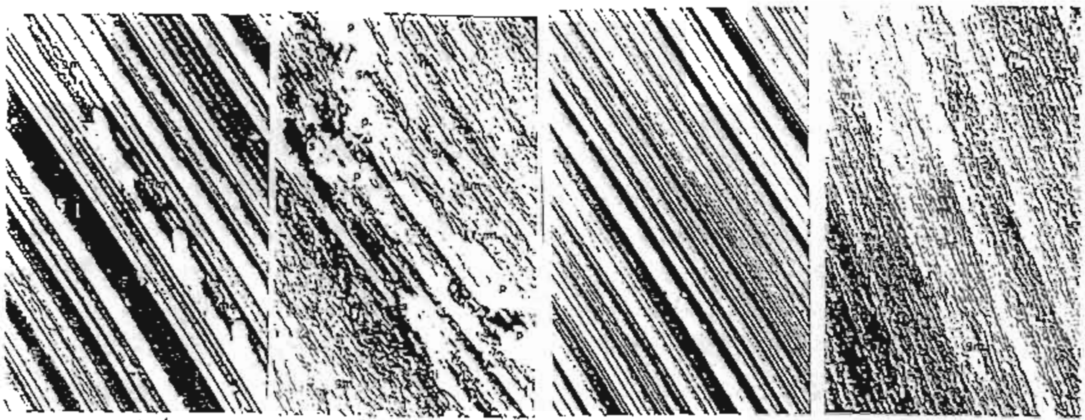


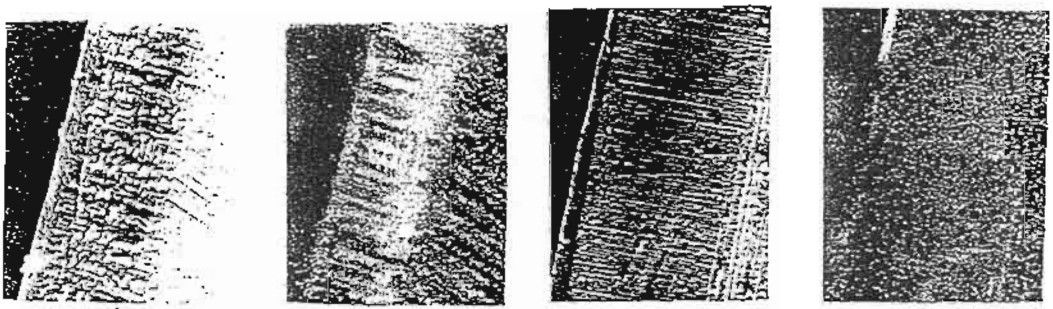
Fig.(5) Comparison of experimental results with an ideal roughness.



(a) sharp (b) worn (c) sharp (d) worn

Fig(6) a,b Milled surfaces at speed of 176 m/min and feed of 0.1mm/tooth using sharp and worn TTM P30 tool respectively.

c,d Milled surfaces at speed of 176 m/min and feed of 0.1mm/tooth using sharp and worn THR K 30 respectively.



(a) (b) (c) (d)

Fig.(7)
(a) and (b) the worn minor cutting edge and its x-ray distribution image of iron for the TTM tool.
(c) and (d) the worn minor cutting edge and its x-ray distribution image of iron for the THR tool.

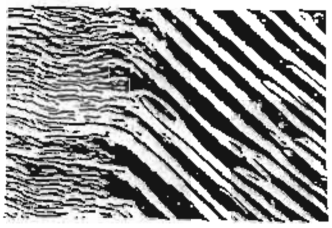


Fig (8) Micrograph showing the nature of the chips from low alloy steel using a worn tool of THR at cutting speed of 176 m / min. and feed of 0.1 mm / tooth.

SEM micrographs showing the segmented chips and fine lamellar on the free surface.