STUDY ON BURR FORMATION IN TURNING

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Abstract: *Several deburring processes have been used for burr removal, rising the cost of the part machined and affecting productivity. Deburring processes depend on the type of burr formed and includes grinding, chamfering among others. Although important in machining operations there are few works concentrated on burr prevention, elimination or minimisation. The complexity of the parameters involved and the difficulty to control them have directed the works to the effect instead of to the cause of burr formation. According to the literature it is impossible to avoid burr formation, however, it can be possible change some characteristics and properties of the burrs to facilitate its reduction after the cut or to decrease its dimensions to acceptable magnitudes. This work presents a study of burr formation for semi-orthogonal cutting operation of carbon steel. The burrs are analysed and measured using scanning electronic microscope and tool microscope. The results showed that the cutting conditions and tool geometry control the characteristics of the burrs. Feed rate and entering angle are the main cutting parameters affecting burr dimensions. Microhardness results also show that the material is highly hardened during the process of burr formation.*

Keywords: Burr, Turning, Machining

1. Introduction

Burr formation is one of the main problems on cutting operations of metals. It is detrimental to the cut and can cause premature failure of the tool, geometrical error in the workpiece and may result in a serious problem on assembly. One of the six tool wear mechanisms mentioned by Trent (1984), called notch wear, can be caused by burr formed during the cutting operation (Nakayama and Arai, 1987). Burr is also a risk for the operator and a problem for automatic operations. It is therefore necessary subsequent operations to get rid of the burrs to achieve the final dimensional and geometric workpiece tolerance. Deburring can be an automatic process, however, many of them are manmade operations. For both cases the result is an increase on production cost and reduction on productivity.

Despite the importance of burr formation on metal cutting, there are very few works about the mechanism of its formation. The works are concentrated on deburring processes instead on burr formation mechanism or ways to eliminate or minimise it during the machining operation.

Gillespie and Blotter (1976) may be exception of this. They have done very important work on this subject, proposing simple analytic models to predict some burr properties and geometry such as height, thickness and hardness. According to their models the burr geometry depends on the properties of the workpiece material particularly the moduli of elasticity and the geometry of the tool, including cutting edge radius. They indicated four basic mechanism for burr formation: deformation of the material on the direction of the cutting edge; chip curling on the cutting speed direction (during the exit of the tool at the edge of the workpiece); the separation of the chip from the workpiece during chip formation; the interruption of the cut at the edge of the tool due to lack of fixation. According to these mechanisms they divided the burr into four types: Poisson burr, roll-over burr, tear burr and cut-off burr. They have concluded that it is impossible to eliminate the burr during the operation by changing parameters like cutting speed, feed rate or tool geometry, but it can be possible to minimise burr geometry. According to Hashimura *et al*. (1995), for example, the thickness of the roll-over burr decreases and the height of the Poisson burr increases when the tool back rake angle increases.

Nakayama and Arai (1987), studied orthogonal cut of an annealed brass and proposed two different systems of burrs classification. They are based on the cutting edge involved on the burr formation and in the mechanism and direction of its formation. In relation to the cutting edge directly concerned in the burr formation they are classified into main cutting edge burr and side cutting edge burr. For both cutting edges involved in the process, the burrs formed are also classified according to the direction and mechanism of their formation into backward burr or entrance burr, sideward burr, forward burr and leaned burr. Studying the effect of the cutting conditions on the characteristics of the sideward burr, they concluded that it is possible to decrease burr height and thickness decreasing underformed chip thickness and chip shear deformation (by increasing rake angle or cutting speed or applying cutting fluid) as it depends on the depth of cut and the stress during shearing of the material in the primary shear plane angle.

Ko and Dornfeld (1991), in a theoretical and experimental work on burr formation at the end of the cut (roll-over burr) during orthogonal cutting of ductile materials, proposed a model to predict height and thickness of the burr as a function of cutting conditions, tool geometry and workpiece material. A mechanism similar to the foot formation phenomena proposed by Pekelharing (1978) for milling operation. However, it is necessary to know previously the primary shear plane angle and the chip tool contact length. They assure that burr height and thickness decrease when the tool rake angle increases and the undeformed chip thickness decreases. The material properties such as yield strength, ultimate yield strength and strain hardening are very important in defining burr size, as the mechanism of burr formation depends on the behaviour of the workpiece material during the cut.

According to the works done on burr formation it is evident that it is impossible to eliminate the burr, however, they can be minimised by the use of correct parameters like cutting conditions, tool geometry, cutting fluid and the properties of workpiece material.

This work shows the effect of some cutting parameters on the geometry and shape of burrs when turning carbon steel AISI1045. It also discusses some characteristics of the burrs formed and the mechanism of their formation.

2. Experimental Procedure

The cutting operation used was the external cylindrical turning with single point cutting tool. Carbide cutting tools coated with TiN with ISO specification SNMG 120408 and a tool holder ISO PSSNR 2020 K12, with the final geometry: $\gamma_O = 7^o$, $\alpha_O = 11^o$, $\chi_r = 45^o$, r = 0,8 mm were used. For all the tests these geometry were constant, except when the entering angle was changed. For this case the variation of the angle was achieve by changing the position of the tool holder. The operation was carried out on a IMOR MAXI II-520 lathe, with 5 kW of power.

The workpiece material was a AISI1045carbon steel, with average hardness of 206 HV and chemical composition according to Tab. (1).

Table 1. Chemical composition (weight %) of the workpiece material.

C	Si	Mn	Cr	Ni	Mo	Cu	Al	P	S
0,48	0,24	0,70	0,10	0,07	0,02	0,04	0,027	0,024	0,020

The workpieces in the form of flanges have initial external diameter of 100 mm and thickness 10 mm. The maximum surface roughness before the test, measured by the Ra parameter, was controlled to be kept less than 10 µm. It was also machined only samples with radial errors smaller than 0,01 mm and axial errors smaller than 0,005 mm. It was used a sample holder designed to minimise the errors due to incorrect set up. The device is described in Kaminise et al (2001). The samples were prepared to the final geometry before the test using this device. These precautions have the objective of avoiding the effect of the workpiece geometry and set up errors on the results.

Table 2 presents the cutting conditions used in the tests. The tests 1 to 6 were done with different cutting speeds, while tests 7 to 11 the feed rate was variable. For tests 12 to 16 the parameter changed was the depth of cut and finally for tests 17 to 19 the entering angle was the variable. All the remaining of the cutting conditions was held constant. No cutting fluid was used in the tests.

It was measured the height and thickness of the burr formed using two different procedures. First they were measured directly from the workpiece using a gauge indicator with graduation of 0,005 mm to measure the height. The measurements were done in 6 different positions along the circle, at 60^o from each other, and the final result was the average. In the second method, small samples were cut from the workpiece to be observed in the optical microscope. First they were mounted in resin, and then polished using different mash sand paper (n^o 80, n^o 240, n^o 600 and n^o 1000). After that they were polished with diamond past of grade 1 µm. The thickness and height were measured in the optical microscopic. Samples of the workpiece were also analysed in the scanning electron microscope before this preparation.

It was observed two different kinds of burrs: in the face of the workpiece where the cut starts when the tool first contacts the workpiece (entrance burr) and in the face where the cut finishes, when the tool loses contact with the workpiece (exit burr). These two kinds of burrs will be referred here as sideflow burr and leaned burr, for the entrance burr and exit burr respectively, according to the classification proposed by Nakayama e Arai (1987). Figure (1) shows an illustration of the positions of these two kinds of burrs encountered in this work.

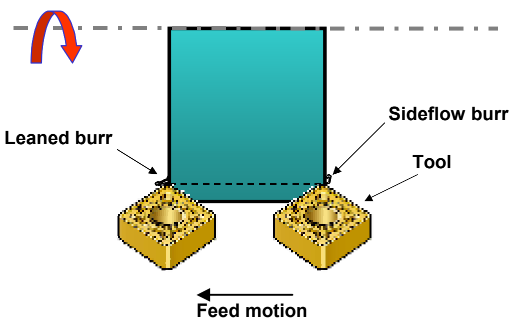


Figure 1. Leaned and sideflow burrs observed in the workpiece in a turning operation.

Microhardness was measured for the leaned burr in about 30 different positions. It was measured microhardness in the burr and also in the region close to it in the bulk of the material. The results for all the samples are shown in Tab. (3) except for sample 14. The positions of the indentations are according to the diagram of Fig. (2).

Table 2. Cutting conditions used in the experimental tests.

Test number	f (mm/rev)	Vc (m/min)	a_p (mm)	χ_r (deg)
1	0,215	**93**	1,00	45
2	0,215	**115**	1,00	45
3	0,215	**144**	1,00	45
4	0,215	**167**	1,00	45
5	0,215	**231**	1,00	45
6	0,215	**288**	1,00	45
7	**0,138**	185	1,00	45
8	**0,323**	185	1,00	45
9	**0,431**	185	1,00	45
10	**0,554**	185	1,00	45
11	**0,646**	185	1,00	45
12	0,215	185	**0,55**	45
13	0,215	185	**0,78**	45
14	0,215	185	**1,00**	45
15	0,215	185	**1,50**	45
16	0,215	185	**2,00**	45
17	0,215	185	1,00	**20**
18	0,215	185	1,00	**70**
19	0,215	185	1,00	**85**

Table 3 – Microhardness results, Kgf/mm^2.

Position	Sample																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	18	19
A1	265	243	209	220	227	247	242	285	270	231	322	221	291	306	268	268	238	222
A2	316	244	270	267	298	275	296	215	256	213	289	201	222	219	284	244	289	234
A3	306	214	338	256	293	284	314	335	356	220	291	211	261	333	268	189	324	259
A4	335	310	338	284	228	280	294	369	222	230	292	256	236	270	264	235	267	200
A5	261	296	316	272	308	268	308	267	304	304	302	265	329	278	193	282	267	200
A6	289	285	320	255	252	291	212	292	316	272	238	284	268	204	267	282	316	215
A7	285	268	215	239	277	285	268	335	356	221	192	209	231	259	235	199	231	227
A8	246	209	-	267	277	308	240	265	300	217	296	177	298	278	377	359	228	285
B1	243	247	235	270	194	243	187	267	228	282	320	183	259	289	190	264	221	182
B2	304	253	261	289	249	268	209	391	228	275	324	195	267	202	220	249	261	223
B3	308	175	205	280	231	240	277	261	232	275	282	220	144	249	289	230	273	231
B4	316	230	246	267	296	214	268	344	273	242	289	262	214	249	252	217	273	235
B5	235	282	182	240	318	249	-	284	259	249	302	338	191	246	300	308	306	247
B6	242	322	320	329	267	250	-	326	230	277	204	292	230	221	261	291	285	289
B7	333	226	273	312	243	209	239	296	273	277	300	187	234	209	197	261	228	302
B8	287	255	-	284	275	249	195	284	179	262	242	300	261	219	261	259	249	275
C1	273	275	211	230	282	186	262	270	220	268	278	174	189	236	186	243	238	261
C2	236	223	255	198	292	289	225	236	200	310	262	211	247	249	242	275	234	220
C3	231	207	243	318	291	226	235	338	284	261	226	220	202	242	316	176	203	249
C4	285	238	284	252	270	264	275	318	302	236	292	338	232	284	268	265	212	238
C5	282	201	236	335	306	275	291	242	302	186	221	234	300	270	-	212	222	285
C6	268	253	282	267	220	277	268	282	312	232	235	314	186	316	265	214	205	226
C7	329	244	186	243	292	231	291	275	304	180	201	316	223	215	239	231	193	244
C8	255	220	-	291	222	242	178	255	285	256	163	278	220	284	282	199	270	249
D5	-	-	214	284	239	-	-	-	-	-	-	-	-	285	-	331	-	-
D6	349	222	188	292	268	236	284		277	174	230	209	242	272	231	267	242	186
D7	255	195	177	277	333	175	289	268	268	220	249	214	249	235	258	267	219	253
D8	293	183	-	256	194	242	223	273	289	199	275	242	168	195	226	223	180	209
E6	191	264	236	275	298	275	291	-	209	188	261	246	280	308	182	253	195	262
E7	275	219	275	209	226	275	247	243	182	235	166	259	234	230	244	234	209	246
E8	240	225	217	291	177	180	173	289	211	262	191	191	212	242	242	262	175	195

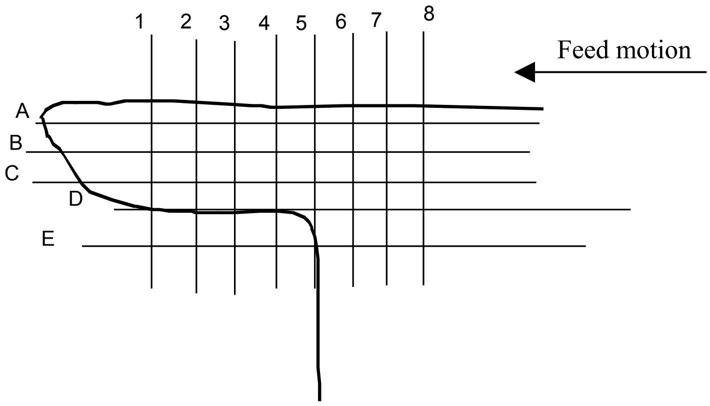


Figure 2. Positions of indentations in the leaned burrs for the microhardness test.

3. Results and Discussions

The sideflow burr is caused by the fact that the material under compression will deform perpendicular to the direction of the applied force, similar to what happens in a hardness test in a ductile material, (Gillespie and Blotter, 1976). The tool cutting edge has a small radius, even for a sharp tool, and when it penetrates into the workpiece the material will flows in the cutting edge direction. This kind of burr was therefore named Poison burr by these authors, as it depends on the Poisson ratio of the material.

Sideflow burrs can be observed in scratch tests. Figure (3) shows the profile of a surface of aluminium machined under special cutting conditions. It was used a high speed steel tool in a pendulum machine. The test aimed to measure the power involved in the cutting process and to test the effect of different cutting fluids. It was used a depth of cut of about 100μm. According to the figure the height of the burr formed is around 120μm. The material that forms the burrs is the material displaced by the tool and also material deformed perpendicular to the direction of the cutting speed.

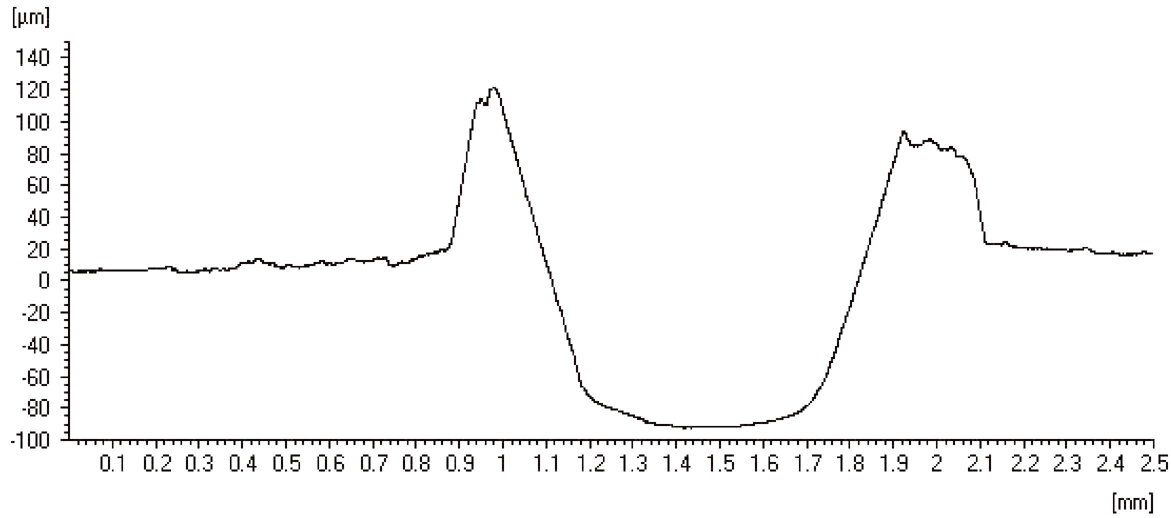


Figure 3. Profile of a scratch produced by a pendulum in a surface of aluminium.

Considering a tool with a rounded cutting edge instead of a sharp wedge, when it touches the workpiece, and before it starts to cut, the movement is similar to the ploughing action of a hard particle sliding against a rigid plastic body (Hokkirigawa, K. and Kato, K., 1988). In this case the ridge of the deformed material is pushed ahead of the slider and no material is removed from the surface. Instead the material flows beneath the particle. Three modes of sliding can be distinguished: cutting, wedge formation, and ploughing. The rake angle and the conditions of the interface determine the transition between them, (Sedricks and Mulhearn 1963). There is no cut when the tool first contacts the workpiece material. It is necessary a minimum penetration of the tool into the material before a chip starts to form. That is because the stress increases from zero until it reaches the strength of the workpiece material and then starts to cut. The Poison burr mechanism starts just when the workpiece-tool contact is established, the burr then formed can be observed at the edge of the workpiece. The action of the tool against the workpiece causes the flow of material to the sides, in the cutting edge direction.

As a result of the mechanism proposed in the last paragraph, the size of the sideflow burr depends on the proprieties of the workpiece material, geometry of the cutting tool, the cutting conditions and the lubrication conditions. The cutting conditions in turn affect the properties of the material, because the temperatures involved in the process and the high strain and strain rates imposed to the material. The mechanism by which the material deforms under such conditions are at the moment unknown.

The effects of cutting speed and feed rate in the thickness of the entrance burr are presented in Fig. (4). These results were obtained using the second methodology described before. The thickness was measured at the base of burr.

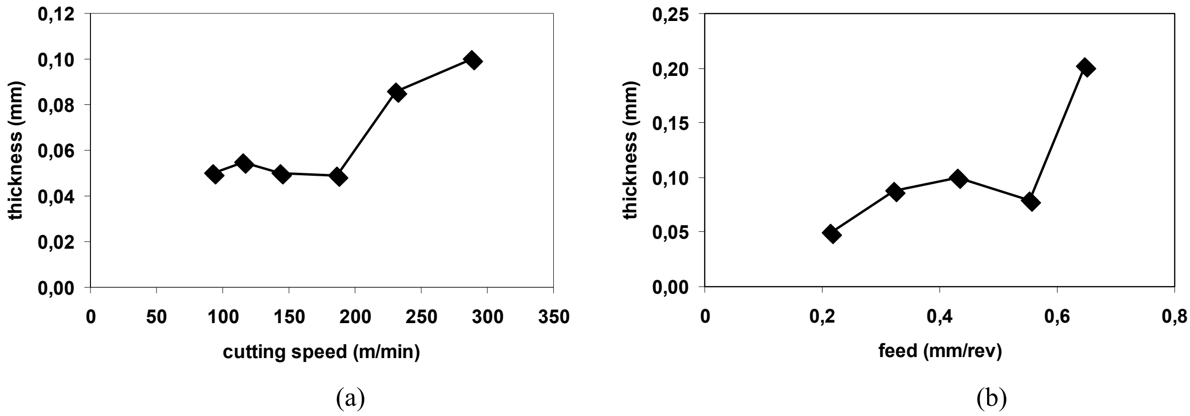


Figure 4. Effects of cutting speed (a) and feed rate (b) on entrance burr geometry.

According to Fig. (4a) the burr thickness increases with cutting speed and it seems that this effect is more pronounced after the cutting speed reaches about 200 m/min. An increase on cutting speed means an increase on temperature, which affects the strength and ductility of the workpiece material as shown when measuring cutting force against cutting speed. The result is that the deformation of the material increases before fracture. However, according to results of tension stress test, an increase on strain rate decreases the deformation of the material, however the behaviour of the material in machining cannot be assumed to be like those laboratory tests.

As the feed rate increases the burr thickness increases, as shown in Fig. (4b). This curve also suggests that the effect is more pronounced after 0,6 mm/rev. The cutting forces are proportional to the feed rate. The increase on feed rate increases the stresses acting in the cutting zone and also the temperature, therefore increasing deformation of the material.

Tool geometry is an important parameter affecting the dimensions of the entrance burr, mainly the nose radius and flank wear, (Form and Beglinger 1970). Tests with different entering angle were also carried out in this work, and the results are shown in Fig. (5). These results were also obtained using the second methodology described and the thickness was also measured in the base of the burr. It is observed that burr height and thickness is proportional to the entering angle. For this work an increase in the entering angle means a decrease in the side angle, as this angle was adjusted changing the position of the tool holder. It means more restriction to the increase of the burr, as the side cutting edge is a barrier to the burr growth and causes an increase in the stress imposed to the material. However, when the burr gets to the tool nose when the tool had completely penetrated into the workpiece, the burr is already formed and maybe there is no difference what the value of the side cutting angle is and there will be no more effect of the tool in the burr size but its geometry. Increasing the entering angle therefore leds to an increase on the stress in the contact between tool and workpiece during the entrance burr formation, increasing its thickness and height.

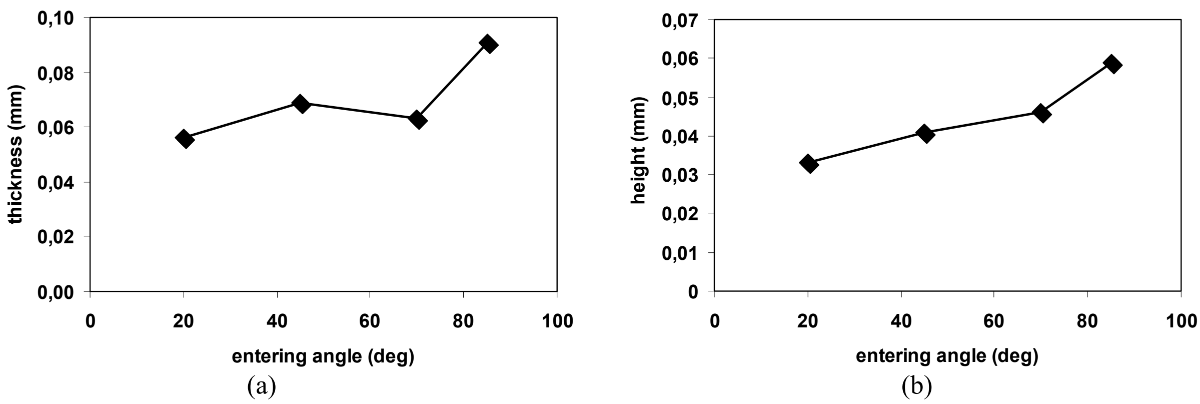


Figure 5. Effects of entering angle on the sideflow burr (a) thickness and (b) height.

Another kind of burr, called leaned burr or roll-over burr (Gillespie and Blotter, 1970), was observed at the end of the cut operation, when the tool leaves the workpiece, in the feed direction, as illustrated in Fig. (1). Observations of the workpiece into the scanning electron microscope suggest that it is a material bending by the tool in the direction of the feed due to the feed force. Figure (6) shows SEM photographs obtained for the sample of the test number 19, according to table 2. It also shows a photograph of the cross section of the burr, obtained by optical microscope. Both photos have a magnification of 50 times.

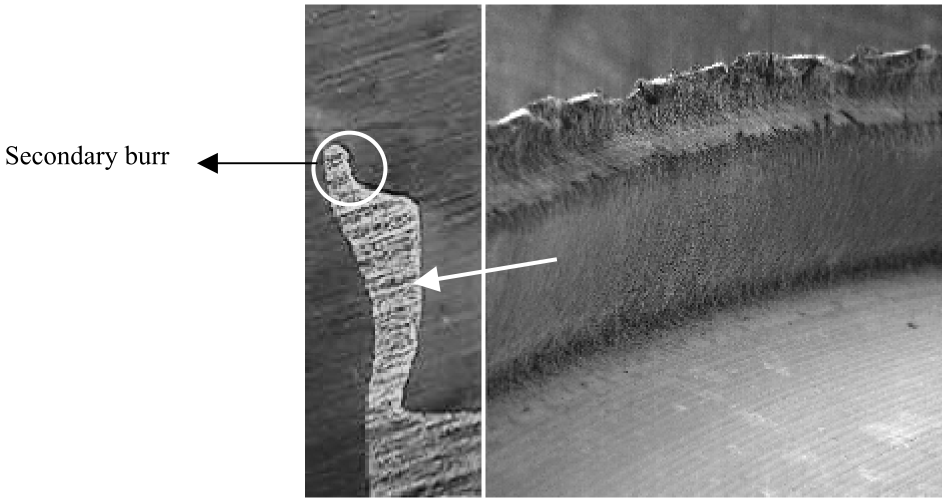


Figure 6. Photographs of burr formed at the end of the cut in the test number 19, magnification 50x: (a) optical microscope of cross section and (b) SEM.

The material of the burr did not pass over the primary shear zone to form the chip because there is no sufficient material ahead of it to support the stresses imposed by the tool in the feed direction. Therefore this material tends to bend, like a cantilever. It means that the size of the burr is strongly dependent on the feed force and the strength of the work material. If the material ahead of the cutting zone has no sufficient resistance to support the stress necessary to continue the cut this portion of material will bend. This is similar to a spinning operation in a forming process. The minimal thickness of material ahead of the tool, necessary to form the burr, was already predicted by Dornfeld (1991), based on the resistance of the workpiece material.

Observing the shape of the burr in Fig. (6a) it suggests that a secondary burr is formed. After the material deforms to form the burr the movement of the tool continues to cut some material until a secondary burr is formed.

The burr formation normally is associated to a chip that is pushed by the tool in the feed direction instead of being sheared. This mechanism is also similar to the foot formation mechanism in milling operations, as described by Pekelharing (1978). According to this mechanism, the burr height should be proportional to the depth of cut. This was confirmed in the present work as shown in Fig. (7), that also shows that the burr height was approximately equal to the depth of cut.

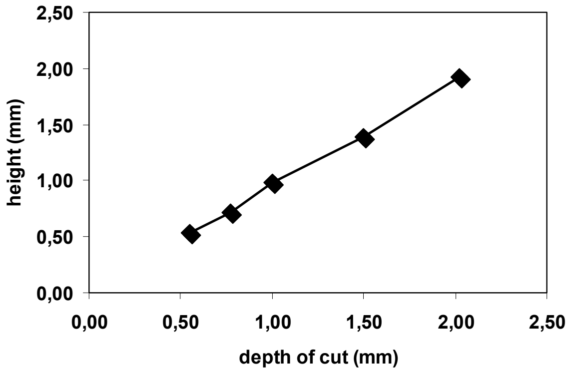


Figure 7. Effect of depth of cut in the height of the leaned or roll-over burr.

The formation of the leaned burr involves, among others, the strength of the portion of material that bends to form it. Therefore an increase in the entering angle means that the cut section is more uniform, which means that the strength of the section does not depend of the position along the depth of cut and therefore the burr height increases, as shown in Fig. (8).

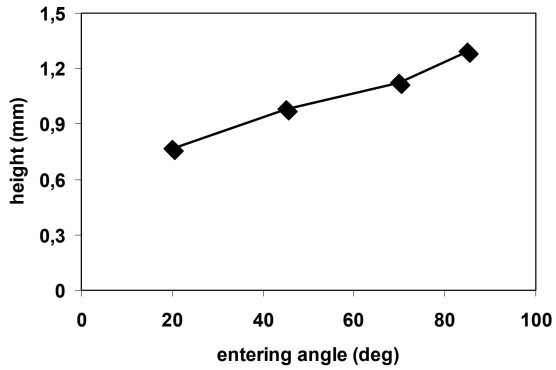
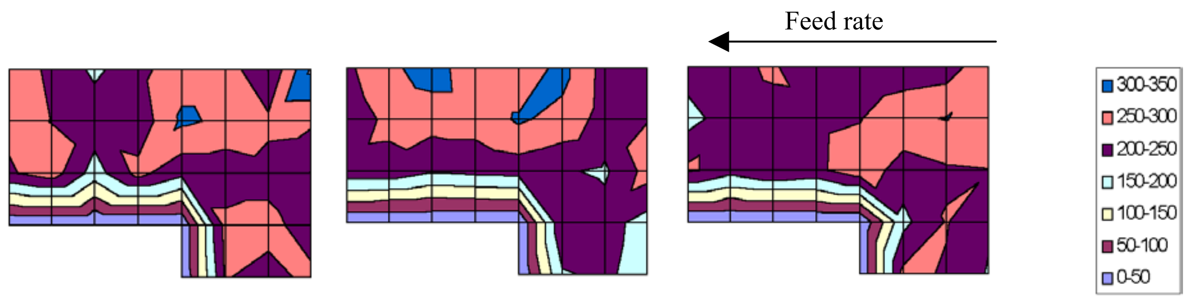


Figure 8. Height of leaned burr in function of the entering angle.

In the tests of Fig. (8) it was used a depth of cut of 1 mm according to table 2 (tests 14, 17, 18 and 19). The results show, however, a burr height bigger than the depth of cut for angles higher than 45°. For these conditions the burr formation mechanism is not simply the bending of the portion of material ahead of the tool at the end of the cut. According to Fig. (6a), it seems that the material bends to form the primary burr, and there is a small portion of material in the burr that bends again to form a kind of secondary burr at the top of the first one. The material that bends due to the feed force will be further machined to form another small burr. The result is a height larger than the depth of cut.

The thickness of the leaned burr is related directly to the feed rate and the entering angle. The feed force increases with feed and therefore the thickness of the burr also increases with the feed. However the burr thickness is not uniform and it is therefore difficult to measure it.

The microhardness results, table 2, suggest a hardness distribution similar to the ones shown in Fig. (9), for samples 17, 18 and 19. The variable parameter for these tests was the entering angle. The distributions are shown diagrammatically, considering the burr has a perfect rectangular shape.



Figures 9 – Microhardness (Kgf/mm2) distribution for samples 17, 18 e 19, effect of entering angle, see Tab. (2).

4. Conclusions

The results obtained in this work allow the following conclusions to be taken:

-The thickness of the entrance burr is affected by the cutting speed, feed rate and entering angle, increasing with theses parameters as it depends on the relative velocity and tool geometry;
-The height of the entrance burr is highly affected by the entering angle. The other cutting conditions such as cutting speed, feed rate and depth of cut have small effect on it.
-The thickness of the leaned burr depends on the feed and entering angle and involves other mechanisms apart from the bending of the chip.
-The depth of cut and entering angle affects the height of the burr.

5. Acknowledgements

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