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RESEARCH PAPER

The Influence of Cutting Edge Angles Included Angle and Nose Radius on Surface Finish of Aluminum Alloy 1050 in Turning.

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A B S T R A C T:

The tool geometry is one of the most effective factors on the surface quality of turned products. This study aims to investigate the influence of different tool geometries on surface roughness of turned aluminum alloy 1050 that has not been documented well in literature. Various levels of simultaneous cutting edge angles, included angle and tool nose radius were selected. Different single point tools of HSS (5% cobalt) were prepared. Four categories of experiments were performed according to the levels of the included angle. Each category consisted of five sets of tests based on the proposed levels of tool nose radius. The tests within each set were arranged according to the selected levels of end cutting edge angle with constant or simultaneous cutting edge angle. All tests were conducted on a heavy duty lathe machine, while the produced surface qualities were measured by a stylus type roughness tester. Experimental results deduced a proportional relationship between surface roughness and end cutting edge angle with constant cutting edge angle. Also, the results showed that the surface roughness increases with the increase of simultaneous end cutting edge angle up to a certain point called focus point angle after which decreases. Furthermore, the tool nose radius has an inverse effect on roughness, but the included angle affects positively. Finally, the maximum values of simultaneous end cutting edge angle that can produce acceptable surface finish were defined in accordance with the tool nose radii and included angles.

KEY WORDS: Surface roughness, Side cutting edge angle, Simultaneous cutting edge angles, Included angle, Nose radius, Turning process..
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ABBREVIATIONS

The tool angles, Figure 1, are specified according to ISO 3002 (1977):
CEA: Cutting edge angle [it is supplementary of (ECEA + IA)]
ECEA: End cutting edge angle
SCEA: Side cutting edge angle [complementary of CEA]
IA : Included angle (or tool nose angle)
r : Tool nose radius (or corner radius)
Ra: Arithmetic average of roughness.
L : Evaluation Length taking on x-axis parallel to the mean line direction.

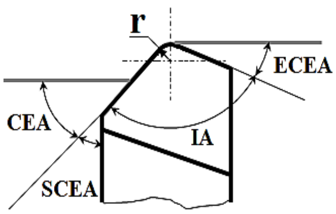

Figure 1: Tool angles in the tool in hand system (ISO 3002, 1977)

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INTRODUCTION

Aluminum alloy 1050 is the common type of aluminum that is utilized in the food, electrical and chemical industries because of its high electrical conductivity, corrosion resistance, and workability. The structural parts of aluminum alloy 1050 suffer from wear during service operations due to roughness and friction. Surface finish is the cheaper and easier factor for improving the wear resistance, frictional resistance, heat transmission ability and fatigue strength or creep life of the machined parts as reported by Mital and Mehta (1988), Rzgar M. A. (2010) and Rao et al. (2013). Ideal roughness in machining processes, among which turning process, is a function of cutting parameters and tool geometry, therefore, the proper setting of tool geometry guarantees high surface finish (Ahmed S. A.; Ramadan H. G., 2017).

Tool shape includes different kinds of angles and geometries, e.g., cutting edge angles, included angle, nose radius etc. The long history of turning process and its importance in machining resulted in a very rich literature in optimizing and selecting the proper geometries of single point tool and hence improving the turning performances of high surface finish and precise dimension. Groover (2007) reported that lower ECEA significantly produces better surface quality. Sung et al. (2014) performed an analytical and experimental investigation about the effect of ECEA on surface roughness of AISI 304 alloy steel rod in finish turning. They deduced that decreasing ECEA considerably improves the surface quality and they found good agreement between the experimental and analytical results.

Also Rico et al. (2010) studied the effect of SCEA on surface roughness of aluminum 1350 in turning operation. Their results show that the SCEA has a significant effect on surface roughness. Moreover, Kolahan et al. (2011) considered both the side and end cutting edge angles during an experimental study to optimize different machining and tool geometry parameters in turning AISI1045 steel. After analyzing the results, they deduced that the optimal surface quality is function of the lowest value of the ECEA and inversely the highest value of SCEA. Surya and Atla (2015) experimented with the influence of CEA of face milling cutter on surface finish of En31 steel material and pointed out linear proportion between them. They explicated the reason due to the increase in the thickness of uncut ridges. Bougharriou et al. (2014) revealed that highly cold worked ridges, corresponding to the tool nose geometry, are left behind on the turned surface with a pitch equals the axial feed.

Regarding the effect of tool IA on surface roughness, Taha et al. (2010) utilized rhombus and triangle inserts of 80° and 60° included angle, respectively, for turning AISI D2 steel at different feed rates. They found that the rhombus type, compared to the triangle, produces 40% higher roughness because its ECEA is larger and causes shallower feed marks. Also, Vasista et al. (2016) used different carbide tip brazed cutting tools of 90^0 , 60^0 , 30^0 nose angles to investigate experimentally their effect on surface roughness of 58CrV4 steel at varied feed rates under dry conditions. They deduced the insignificance of included angle to surface roughness at low feed rates and also the importance of the 60° nose angle tools for profile turning applications.

The importance of the tool nose radius, as the tool geometry factor, in producing acceptable surface finish had also been investigated by many researchers. In a review paper Chaijareenont and Tangjitsitcharoen (2018) concluded that large nose radius produces smoother surface at low feed rates and a high cutting speeds, however it increases the ploughing effect in the cutting zone and the tool flank wear. Singh et al. (2016) studied and analyzed effect of different nose radius (0.4 mm, 0.8 mm, 1.2 mm) of the CNMG cutting tool on surface roughness of aluminum (6061), in CNC turning and dry condition. They deduced that nose radius is the most significant parameter to surface roughness; it decreases with the increase in nose radius.

Lubis et al. (2015) studied the influence of different nose radius of 0.4 mm; 0.8 mm and 1.2 mm of three carbide cutting tools on the surface roughness of steel ST60, using spindle CNC machine and coolant cutting APX. They deduced that the tool nose radius of 1.2 mm performs the lowest roughness of 1.67μm. During an experimental investigation on the dry facing operation of an Al-Cu alloy, Torres et al. (2015) considered different tool nose radius values of up to 1.2 mm to analyze its impact on surface roughness. They found that the larger tool nose radius causes a smoother feed marks and improves surface finish. In contrast Chaijareenont and Tangjitsitcharoen (2018) focused on effect of tool nose radius on surface roughness during turning aluminum alloy (Al 6063). They concluded that surface roughness improves with increasing nose radii to only 0.4 mm and lower, but not more. Therefore, the nose radius is considered as a variable in the current study to determine its effect on surface roughness.

Aforementioned review shows that only the individual impact of the tool geometries, especially the ECEA and CEA, on surface quality have been studied without considering their concurrent change. There is still a lack of information about the effect of nose radius, included angle together with simultaneous cutting edge angles on surface finish of aluminum alloy 1030. Simultaneous means that the tool ECEA and CEA values are changed equally and contrary.

Therefore different levels of simultaneous cutting edge angles, nose radius and included angles are considered and examined in this study to find their effects on the surface quality of aluminum alloy 1050 when turning. The desired values of the simultaneous cutting edge angles are obtained virtually by rotating the lathe machine tool post.

1 EXPERIMENTAL PROCEDURE

1.1 Materials, Machines and Instruments:

The test samples are prepared from a 25 mm diameter shaft of aluminum alloy type 1050 that has shear strength of 60 GPa and its chemical composition illustrated in Table 1.

Table 1: Chemical composition of the sample material

Si	Fe	Cu	Mn	Mg	Zn	Ti	V	Al
0.25	0.4	0.05	0.05	0.05	0.05	0.03	0.05	99.07

This material was chosen due to its ductility. The HSS tools of 5% cobalt, Figure 2, are utilized in order to facilitate implementation the required tool geometry. The inclination, rake and relief angles of the used tools are kept at 3°, 4° and 3°, respectively. All experiments are performed on a heavy duty precision conventional lathe machine, type Excel; model TH8020D of 11kW main spindle motor power.

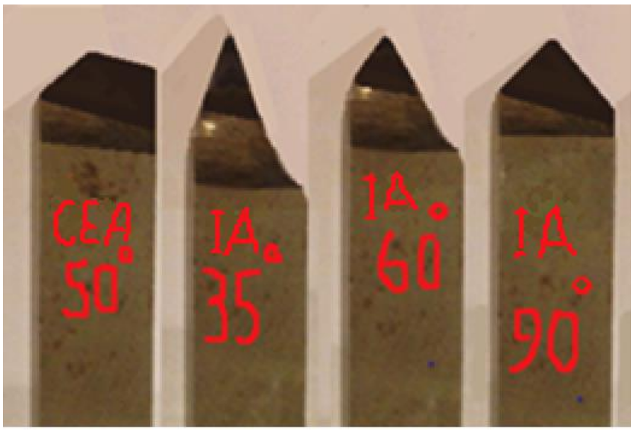


Figure 2: Applied HSS tools.

Surface quality of the test specimens are measured by a stylus type roughness tester, Figure 3, model ISR-C100 and measuring range of 160 µm. A traversing length of 0.8 mm was applied for measuring roughness according to BS1134:2010 (2010). Surface roughness was characterized by the most commonly specified parameter of arithmetic mean surface roughness (Ra), which is obtained from the following relation in micron meter according to UNE-EN-ISO4287:1999 (2010).

$$\mathrm{Ra} = \frac{1}{L} \int_0^L \{f(x)\} dx \qquad (1)$$

The measuring devices of optical profile projector, optical protractor, angle gauge and radius gauge, are utilized to check and ensure the prepared tool geometries of tool angles and nose radius before using.

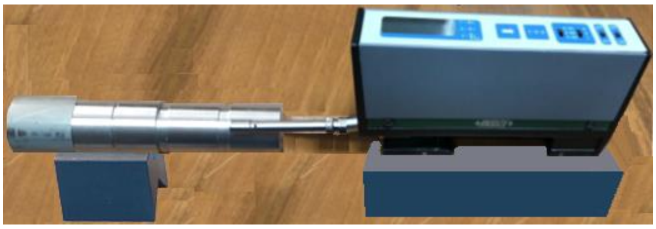


Figure 3: The styles type roughness tester during application

1.2 Experimental set-up

The experimental planning of this study involves a series of tests (200 tests), which are divided into four categories according to the IA values of the utilized cutting tools (Varied, 35°, 60°, 90°). Each experiment category contains five sets of tests according to the selected levels of tool nose radius (0.1mm, 0.2mm, 0.3mm, 0.4mm and 0.5mm). Each individual test set consists of ten tests according to the proposed levels of ECEA, as illustrated in Table 2.

Table 2: The study plan (the proposed variables and their levels).

Test categories					
Test category No		1	2	3	4
IA [°]		Variable	90	60	35
Test sets					
Test set No.	1	2	3	4	5
r [mm]	0.1	0.2	0.3	0.4	0.5
Tests					
Test No	ECEA [°]	CEA[°]			
1	2		88	118	143
2	6		84	114	139
3	10		80	110	135
4	20		70	100	125
5	30	50	60	90	115
6	40		50	80	105
7	45		45	75	100
8	60		30	60	85
9	72.5		17.5	47.5	72.5
10	80		10	40	65

The IA value is varied in the tests of the first test category because the tool CEA is kept constant at 50° and the tool ECEA is variable. Also the tool CEA has different values in the tests of the last three test categories (second, third and fourth) due to its simultaneous change with the ECEA and IA values. The simultaneous values of IA in the first test category and CEA in the last three test categories are determined according to the following relation (Sung et al., 2014):

$$ECEA + CEA + IA = 180° \qquad (2)$$

Prior to each test the HSS tool, as shown in Figure 2, is grinded to its required geometry except the desired simultaneous ECEA and CEA values, in the last three test categories, are obtained practically by rotating the lathe tool post. Then the tool geometry is checked precisely. Constant feed rate of 0.4 mm/rev and cutting depth of 0.12 mm are proposed in order to ensure involvement of the straight main and minor cutting edges during cutting. Also a fixed cutting speed of 20 m/min that ensures good surface finish is applied during the tests. All levels of the proposed test variables (ECEA, IA and tool nose radii) as well as the fixed cutting conditions are selected based on previous experience, characteristics of the cutting tool and the mechanical properties of the test material.

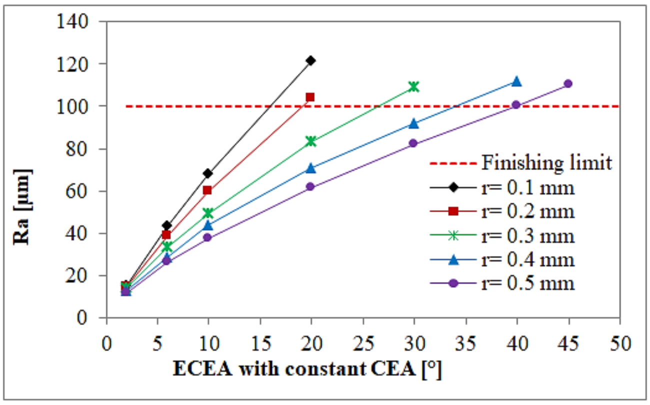
Surface roughness of the samples are measured at three places along the feed direction by rotating the sample about its axis through 90°, then their average are obtained as response variable. A limit of 100 µm is considered for the accepted roughness to allow obtaining clearer data about the effectiveness of the proposed variables on surface roughness. Furthermore, each test is repeated at least three times to obtain more realistic value of the desired response variable of surface roughness.

2 RESULTS AND DISCUSSION

2.1 Effect of ECEA with constant CEA on surface roughness:

Figure 4 exhibits the surface roughness variation by a specified tool of 90° included angle and 50° CEA for different ECEA at different tool nose radius. It shows that the surface roughness of turned aluminum alloy 1050 increases with the increase of ECEA. The increasing rate depends on the tool nose curvature value, which decreases with the increase of its radius. In other words a tool with a specified ECEA and CEA can produce smoother surface, when its nose radius is larger.

Figure 4: Effect of ECEA on surface roughness. CEA = 50°



Accordingly, the maximum ECEA that gives acceptable surface roughness by a tool of 0.5mm nose radius is 40° and reduces to 16° when the nose radius is 0.1mm. This is because the increase of ECEA with fixed CEA increases persistently the height of the produced surface ridges, while increment of the tool nose radius escalates the engaged circular cutting edge that provides smoother finish. Figure 5 shows the produced surfaces of some test samples that are accepted or not according to the proposed finishing limit of this study.

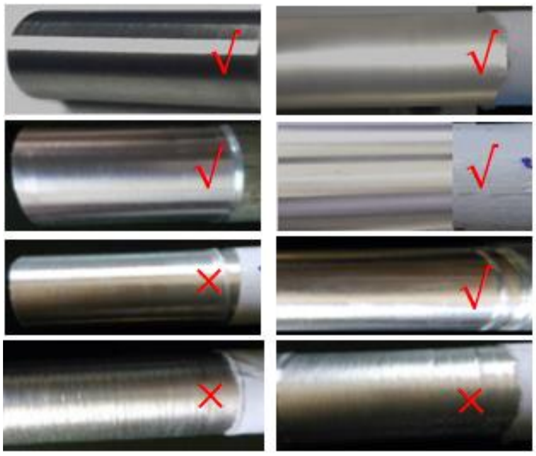


Figure 5: The surface quality of some accepted (√) and unaccepted (×) test samples

2.2 Effect of simultaneous ECEA and CEA on surface roughness:

The relationship between surface roughness of turned aluminum alloy 1050 by three specified tools of 90°, 60° and 35° included angles, for different simultaneous cutting edge angles at different tool nose radii, are illustrated in Figures

6, 7 and 9, respectively. The simultaneous ECEA values are similar in all the three tool types, but the CEA values are differ because they change equally and contrary to the tool ECEA and IA values. All figures, more obvious Figure 6, show that the surface roughness increases with the increase of simultaneous ECEA (or inversely the decrease of CEA) up to a certain point called ‘focus point’ after which reduces. Focus point is the point of equality between ECEA and CEA that can be determined as follows:

$$\text{Focus point angle} = (\text{ECEA} + \text{CEA})/2 = (180° - \text{IA})/2 \qquad (3)$$

Accordingly, the focus point angle for the three tool types of 90°, 60° and 35° included angles are 45°, 60° and 72.5°, respectively. Figure 6 also shows that the tool of 90° nose angle produces acceptable surface roughness (within the suggested limit of this study) at all levels of simultaneous ECEA when the nose radius is 0.4 mm or larger. In contrast when the nose radius is smaller than o.4 mm the surface roughness deteriorates for the tools of 0.3mm, 0.2mm and 0.1mm nose radii at the limited levels of simultaneous ECEA ranging between 25°- 62°, 18°- 66° and 16°- 76°, respectively. This means that the surface roughness improves again at the high levels of simultaneous ECEA and CEA for the 90° included angle tool.

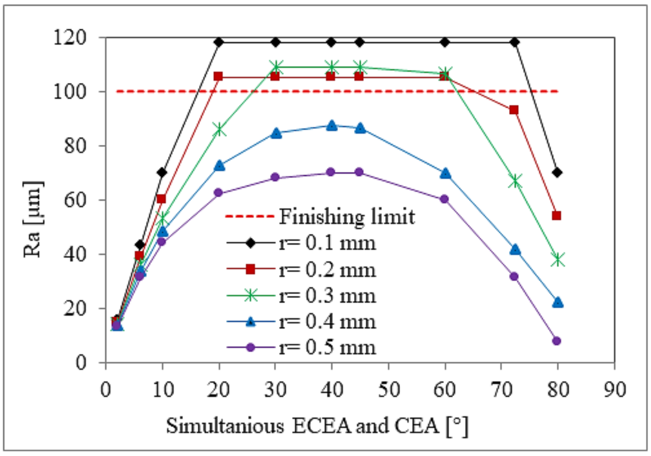


Figure 6: Effect of ECEA with simultaneous CEA on surface roughness, IA = 90°.

Figure 7 exhibits that the tool of 60° included angle produces deteriorated surface, as shown in Figure 8, beyond the simultaneous ECEA values of 30° and 40° at the nose radii of 0.5 mm 0.4 mm, respectively. Moreover, the surface roughness by the tool of 0.4 mm nose radius tends to improve beyond the simultaneous ECEA of 78°. Finally, the maximum active simultaneous ECEA that gives acceptable surface roughness is 42° for the tool of 0.4 mm nose radius, but reduces to 14° when the tool nose radius is 0.1 mm.

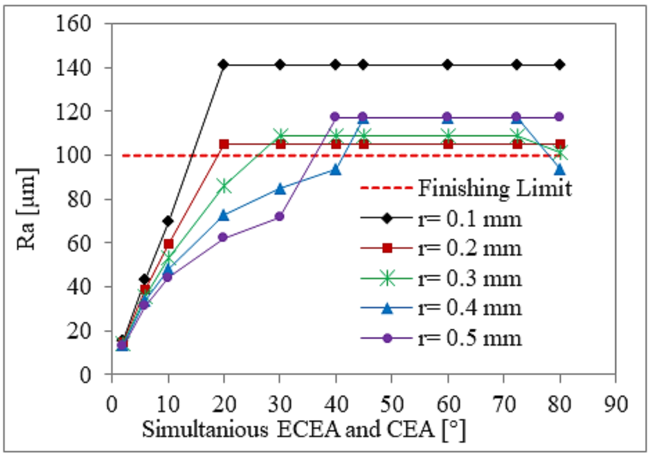


Figure 7: Effect of ECEA with simultaneous CEA on surface roughness, IA= 60°.

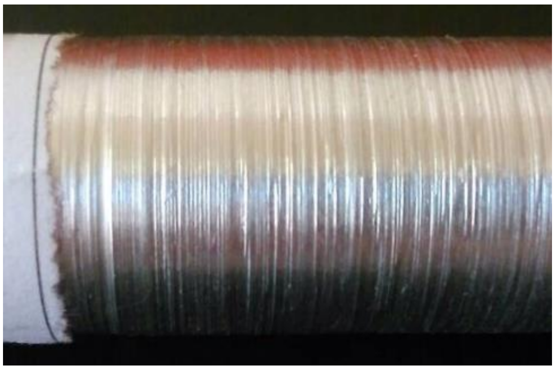


Figure 8: Deteriorated surface (higher than 100 µm) produced by a tool of IA= 60°, ECEA = 50° and r = 0.5 mm.

Figure 9 presents the relationship between the surface roughness, produced by the tool of 35° included angle, and different simultaneous values of ECEA at different nose radii. Although the resulted relationships should be curvilinear, they appear linear as those in Figure 3 because the tool type of 35° included angle has a large focus angle of 72.5°. Additionally, the maximum active simultaneous ECEA that gives satisfied roughness is 42° at the 0.5 mm nose radius tool, but reduces to about 18° for that of 0.1mm. It can be deduced from Figures 6 and 8 that the large focus angle (60° or higher) impedes the improvement of surface roughness at the simultaneous ECEA larger (or the simultaneous CEA lower) than the focus angle.

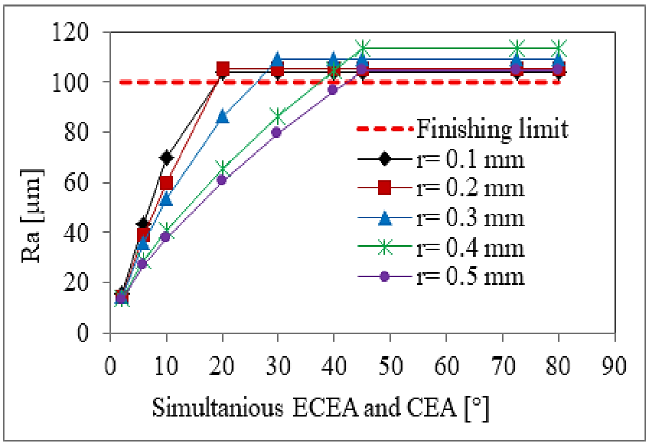


Figure 9: Effect of ECEA with simultaneous CEA on surface roughness. IA = 35°.

Figure 10 shows the effect of different concurrent ECEA on the surface quality of aluminum alloy 1050 by three specified tools of 90°, 60° and 35° included angles and a constant nose radius of 0.3 mm. It presents that despite the difference of IA and CEA in the tools, the simultaneous ECEA has a similar effect on surface roughness up to 30° then differ. This is because the ECEA value approaches the focus angle values that cause different complex engagement of the straight and circular cutting edges. Finally, the proper limits of maximum active simultaneous SCEA that can offer acceptable surface roughness for aluminum alloy 1050 are summarized in Table 3 according to the proposed values of IA tool nose radius.

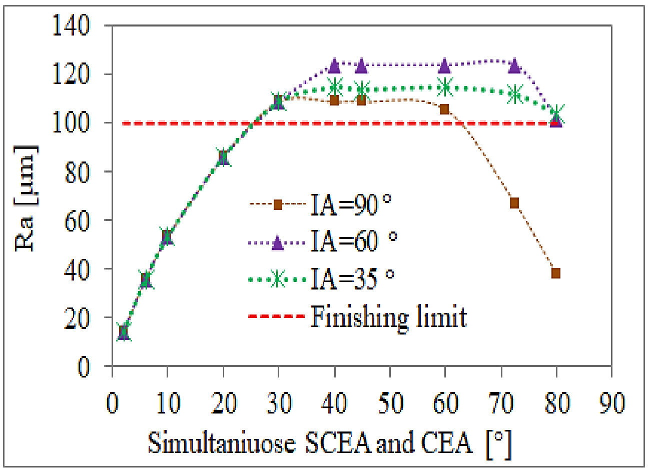


Figure 10: Effect of ECEA with simultaneous CEA on surface roughness by tools of different IA. r = 0.3 mm.

Table 1: The maximum active simultaneous ECEA and CEA that can give acceptable surface roughness

r [mm]	**IA** [°]		
	90°	60°	35°
	simultaneous **ECEA** and **CEA** [°]		
0.1	Up to 16°, then from 76°	Up to 14°	Up to 18°
0.2	Up to 18°, then from 66°	Up to 18°	Up to 18°
0.3	Up to 25°, then from 62°	Up to 25°	Up to 25°
0.4	All angles	Up to 42°, then from 78°	Up to 38°
0.5	All angles	Up to 35°	Up to 42°

2.3 Effect of r and IA on surface roughness:

The effect of tool nose radius on the surface finish of turned aluminum alloy 1050 is illustrated in Figure 11 for the three proposed tool types with constant ECEA of 30°. It shows that the nose radius is the most effective factor and has an inverse effect on surface roughness and the decreasing rates of roughness by the tools are different at the nose radii less than 0.4 mm, but they are similar for those of 0.4 and higher.

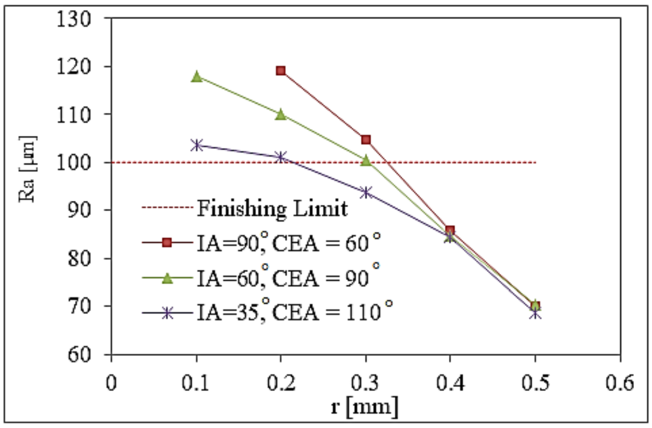


Figure 11: Effect of **r** on surface roughness at different IA. ECEA= 30°

Figure12 exhibits effect of the included angles of 90°, 60° and 35° on the surface roughness at different nose radii. It illustrates that IA has a positive effect on surface roughness for the nose radius smaller than 0.4mm, but it is insignificant for the nose radii of 0.4 mm and larger. This means that the tool with smaller IA produces smoother surface due to the increment of the engaged curved cutting edge that reduces the height of the ridges at the machined surface of the aluminum alloy1050.

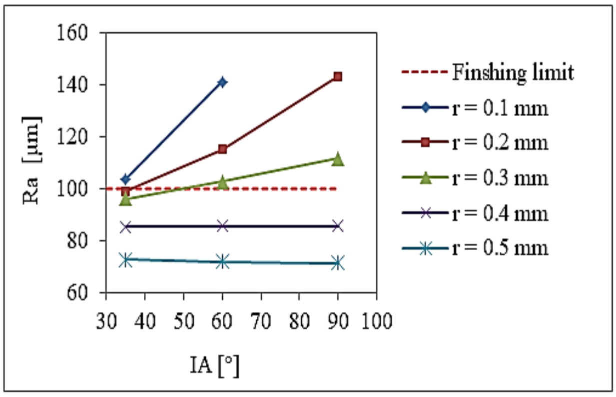


Figure 12: Effect of IA on surface roughness at different **r**. ECEA=30°

3 CONCLUSION

High surface quality, in the turning process, can be achieved by setting the proper levels of the tool geometry. This study investigates the effect of ECEA, with constant and simultaneous CEA, on the surface roughness of aluminum alloy 1050 for different single point tools with various levels of tool nose radius and included angles. The results presented that:

1. Surface roughness increases proportionally with the increase of ECEA, when CEA is constant.
2. When the simultaneous ECEA increases (or the simultaneous CEA decreases), the surface roughness increases up to a certain point called focus angle, then reduces and improves depending on the values of focus angle and tool nose radius.
3. The tools of 90° included angle provides acceptable surface roughness at all levels of simultaneous ECEA, when the nose radius is 0.4 mm or larger.
4. Surface roughness decreases with the increase of tool nose radius and it is the most important and effective tool geometry factor.
5. Included angle has a positive effect on surface roughness at the tool nose radii of 0.3 mm or smaller, but it is insignificant at those higher than o.3 mm.

Finally, further research is recommended about the influence of ECEA with simultaneous CEA on the produced cutting force and tool life, in addition to optimizing the cutting parameters that provides better cutting performances in turning aluminum alloy 1050.

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