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The Effect of Cutting Tool Vibration on Surface Roughness of Workpiece in Dry Turning Operation

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Abstract

This study is to find a correlation between surface roughness and cutting tool vibration in turning. The ranges of process cutting parameters in the present study are limited: cutting speed (34, 70, 130 m/min), depth of cut (0.1, 0.2mm), feed rate (0.07, 0.13, 0.17mm/rev) and tool overhanging (25, 30, 35, 40mm). The data are generated by lathe dry turning of medium carbon steel samples at different levels of the mentioned above parameters. Dry cutting tests (without using cutting fluid) are conducted to simulate a good turning, the dry turning provided a clean environment to obtain undisturbed clear cutting vibration, which results in more accurate and clear correlation between cutting vibrations and roughness. The analysis of variance reveale in this study is that the best surface roughness condition is achieved at a low (feed rate less and equal 0.13mm/rev), and with smaller tool overhang less and equal 30mm). The results also show that the cutting speed has small effect on surface roughness than feed rate and tool overhang. The depth of cut has not a significant effect on surface roughness in this study.

Above results can be obtained when there is no built up edge and no damage of the tool tip. Finally experimental results have shown good correlation between the cutting tool vibration and surface roughness which can be used to control the finish surface of the workpieces during the mass production.

Keywords: Dry turning operation: Surface roughness: Tool vibration.

الخلاصة

هذه البحث لأيجاد علاقة بين أهتزازات قلم القطع والخشونة السطحية في عملية القطع. تم تحديد عوامل القطع في هذه الدراسة بحيث تكون سرعة القطع (١٠٣٠،٥٦٠،٢٧٠ دورة/دقيقة) وعمق القطع (٠,٢،٠,١ملم) ومعدل التغذية (٠,١٧،٠,١٣،٠,٠٧ملم/دورة) وطول قلم القطع (٤٠،٣٥،٣٠،٢٥ملم). تم أجراء التجارب في ماكنة الخراطة بدون استخدام سائل التبريد, وبأستخدام عينات من حديد ذو نسبة كاربون متوسطة عند مختلف حالات القطع. عدم أستخدام سائل التبريد يمثل حالة جيدة لعملية القطع. حيث يعطي وضعية جيدة لحصول على أهتزازات القطع,و النتائج يكون أكثر وضوحا ودقيقا بين أهتزازات و خشونة السطحية. نتائج التحليل في هذه الدراسة يوضح بأن الخشونة السطحية جيدة يكون في حالة معدل التغذية أقل أو يساوي الى ٠,١٣ملم/دورة أما الخشونة السطحية غير جيدة متشابهة(عند بروز أقل أو يساوي ٣٠ملم).

النتائج في هذه الدراسة يبين بأن لسرعة القطع تأثير صغير جدا على الخشونة السطحية مقارنة مع تأثير معدل التغذية. أما عمق القطع فأن تأثيرها ليست ملحوظة على الخشونة السطحية. هذه النتائج يمكن حصول عليها عند عدم لصق الرايش على القلم أو عدم حصول أي ضرر في رأس القلم. في النهية فأن النتائج العملية يبين بأن هناك علاقة جيدة بين أهتزازالقلم و الخشونة السطحية. ويمكن أستخدامها لسيطرة على الخشونة السطحية لشغلة في عمليات اللأنتاجية.

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1. Introduction:

In the turning operation, vibration is a frequent problem, which affects the result of the machining, and, in particular, the surface finish. Tool life is also influenced by vibration. Severe acoustic noise in the working environment frequently occurs as a result of dynamic motion between the cutting tool and the work piece. In all cutting operations like turning, boring and milling, vibrations are induced due to the deformation of the work-piece. This implies several disadvantages, economical as well as environmental [1].

Today the standard procedure to avoid vibration during machining is by careful planning of the cutting parameters. The methods are usually based on experience and trial and error to obtain suitable cutting data for each cutting operation involved in machining a product. Machining vibration exists throughout the cutting process. While influenced by many sources, such as machine structure, tool type, work material, etc., the composition of the machining vibration is complicated. However, at least two types of vibrations, forced vibration and self-excited vibration, were identified as machining vibrations. Forced vibration is a result of certain periodical forces that exist within the machine. The source of these forces can be bad gear drives, unbalanced machine-tool components, misalignment, or motors and pumps, etc. Self-excited vibration, which is also known as chatter, is caused by the interaction of the chip removal process and the structure of the machine tool, which results in disturbances in the cutting zone. Chatter always indicates defects on the machined surface; vibration especially self-excited vibration is associated with the machined surface roughness [2].

A large number of theoretical and experimental studies on surface roughness of machined products have been reviewed where cutting conditions (such as cutting speed, feed rate, depth of cut, tool geometry, and the material properties of both the tool and work piece) significantly influence surface finish of the machined parts [3, 4, 5, 6, 7, 8, 9, 10, 11]. The surface roughness can be affected by built up edge formation. The analysis of tool vibration on surface roughness is also investigated by some authors the purpose of these paper is to investigate the effects of tool vibration on the resulting surface roughness in the dry turning operation of carbon steel[5,6,7]. From the above literature reviews it is observed that many factors affect performance of the turning process and affecting surface quality. There are some differences concerning the influence of few factors on the surface finish. This may be due to different ranges of process parameter as well as different tool job machine combination. In machining operation, the quality of surface finish is an important requirement for many turned work pieces. Thus, the choice of optimized cutting parameters becomes very important to control the required surface quality.[12]

The aim of this research is to investigate the effects of cutting tool vibration on the resulting surface roughness in the dry turning operation of medium carbon steel. To achieve such objective, the research should have completed a fractional experimental design that allows considering a different level interactions between the cutting parameters (cutting speed, feed rate, depth of cut and tool length) on the two measured dependant variables (surface roughness and cutting tool vibration).

2. Experimental Procedure

The work planned and carried out in such a way to provide detailed information on the effect of cutting tool vibration on surface finish in turning operations. The materials and equipment were used in the experimental procedure of this investigation are; the workpiece material type used is cold drawn-medium carbon steel bars shape, the dimensions are 40x3000mm with the following specifications; (*s* yield (min) = 305 MPa, *s* ultimate = 618 MPa, hardness = 168 HB30, and 0.35%C); Turning Machine, high-speed steel (HSS-718, F10 type), cutting tool used the dimension (8x8x12.5mm) type (HSS-718) with the following angles. back and side rake angle is 10º, 12º respectively, side relief angle is 5º and side cutting edge angle is 15º, these angles chosen depend on the standard angles, [13].

3. Cutting Parameter and Workpiece Dimensions.

A factorial design was chosen, so that different interactions between independent variables could be effectively investigated. The independent variables in the study are cutting speed, feed rate, depth of cut and the tool length. The last variable is introduced in to the experiment since we suspect that the vibrations generated by varying the tool length could affect the resulting surface finish since the natural frequencies are modified. The dependent variable is the resulting first cut surface finish and the acceleration in both radial and feed directions. The levels of the independent variables are shown in Table (1)

These levels were selected in order to cover the normal range of lathe cutting operations for plain carbon steel. In order to minimize the effect of tool wear, which could affect the surface roughness quality, the tool was changed after 4 cuts. The newly tool installed was run for a few machining times to eliminate rapid tool wear. 4 cuts, 50mm , were made on each rod sample as shown in Fig. (1) to perform a total of 72 cuts. The specimens were made of same free cutting steel.

4. Vibration and Surface Measurement Device Setup:

A Hottinger SM60 (10) type measurement devise, was used for measuring the amplitude and velocity of a point on the cutting tool. The tool vibration level was measured using a vertical data of a transducer mounted near to the tip and connected to the devices. The data include a displacement (x) and velocity (v) of the indicated point on the tool for each sample. The acceleration was calculated by using general equation between the amplitude and acceleration.

A Tyler Hobson (10) type instrument was used for the measurement of surface roughness. Three different positions for each sample at 120º with each other and the average of the three reading are considered as surface texture of the turned surface.

5. Results and Discussion

The results in this investigation are classified into two categories:

1-The vibration parameters data, velocity and displacement (X,X') in vertical direction.

2-The surface roughness data which were obtained from the surface profile meter device.

There are nine groups of experimental testing and results, each group contains eight tests at different tool overhang and depth of cut. Table (2) shows the cutting conditions which were chosen and the tests were curried out according to these cutting conditions. Each condition repeated with depth of cut (0.1 and 0.2 mm) and for cutting tool overhang (25, 30, 35, and 40 mm).

Frequencies that were obtained practically have been plotted by Matlab computer software.

Fig.(2) shows the frequencies response the time for different overhang. Fig.(3) shows the samples of surface texture at different tests.

The relationship between overhang tools with cutting tool acceleration and the surface roughness of work piece for cutting condition (A, B, C, D, E, F, G, H, and I) is plotted in Figs. (4-a, 4-b, 4-c, 4-d, 4-e, 4-f, 4-g, 4-h, and 4-i) respectively, as well as the figures contain for different tool overhang (25, 30, 35, & 40mm) for vertical direction of acceleration, with depth of cut (0.1mm, 0.2mm as indicated below.

The actual amplitude of the relative vibrations between tool and workpiece can be measured using a displacement sensor. Figs. (4-a, 4-b, 4-c, 4-d, 4-e, 4-f, 4-g, 4-h, and 4-i) has been constructed to illustrate the main effect of cutting tool vibration on surface roughness of work piece. Fig. (4-a) shows the relation between cutting tool vibration and surface roughness of work piece. It is clear that the acceleration of cutting tool has significant effect on the surface roughness of work piece. It was observed that increasing the acceleration of cutting tool through increasing the tool overhang will cause the increase in surface roughness of work piece.

Fig. (4-b) shows that the surface roughness of workpiece is proportional directly to the cutting tool acceleration, but the values of surface roughness are higher if compared with previous case because the feed rate in these cases is higher. Fig. (4-c) indicate the same effect but in this case the change in surface roughness is more, because the feed rate (0.17mm/rev)with cutting tool overhang interactes together and both factors lead to increasing the surface roughness.

With increasing the cutting speed 70m/min and feed rate 0.13mm/rev as indicated in Fig. (4-d, 4-e and 4-f) the cutting tool acceleration and cutting speed on surface roughness of work piece are acting together but they change proportionally indirectly with each other. Fig. (4-d) indicates small change in surface roughness of work piece with change of acceleration. Figs. (4-e) indicates that the relationship between cutting tool acceleration and surface roughness of workpiece is clearer because of increasing the feed rate. Fig. (4-f) shows the significant relationship between cutting tool vibration and surface roughness of work piece at higher feed rate (0.17mm/rev), at high cutting speed 127m/min as indicated in Figs. (4-g, 4-h, and 4-i) the effect of cutting tool overhang on sum roughness disappear. Clearly in these cases the cutting speed has significant effect on surface roughness and it is more effective than the cutting tool overhang effect at any feed rate.

Then from experimental results the vibrations increase and then decrease with increasing in the cutting speed. The factors which lead to increasing the vibrations are such as cutting speed, feed rate and depth of cut, the effects of the feed rate on vibrations is fewer than that of the cutting speed and the depth of cut. The more the tools overhang from the tool holder, the smaller the cross sectional dimensions of the cutting tool and the lower the rigidity of the machine operation system, the greater the vibration results.

This subject has been explained by; J. Lipski, et al.,"The problem of stability in the machining processes is an important task. It is strictly connected with the final quality of a product. In this paper we consider vibrations of a tool-workpiece system in a straight turning process induced by random disturbances, and their effect on a product surface. Using on experimentally, obtained system parameters we have done the simulations; using one degree of freedom model" [16]. This subject also was discussed by; Luke Huang, et al., "Other technologies, such as optical, acoustic, electromagnetic, force, and vibration. However, the optical, acoustic, and electromagnetic technologies are not practical in the machining environment because chips and coolant Therefore, vibration, especially self-excited vibration, is associated with the machined surface roughness. Attempts have been made to use vibration signals in predicting tool wear and tool life in turning operations and other machining operations" [2].

6- Conclusions

This paper has a detailed description of the effect of cutting tool vibration on surface roughness of workpiece. The surface roughness of machined parts is predicted by using the vibration data. The discussion of the results in this investigation can be concluded wuth the following points.

1-Cutting tool acceleration has a significant effect on surface roughness of workpiece. The surface roughness of work piece is proportional to cutting tool acceleration. This effect interacts with other independent variables such as feed rate cutting speed and depth of cut.

2-The acceleration of the cutting tool increases with the increasing of the cutting tool overhang for different cutting conditions. Thus the vibration of cutting tool depends strongly on cutting tool overhang.

3-With the increasing feed rate the surface roughness of work piece will increase. The feed rate can be considered as a main cutting factor in the machining operation.

4-Increasing cutting speed leads to a decrease in surface roughness of workpiece.

5-Depth of cut has small effect on surface roughness of work piece in this study.

6-Parallel to the tool vibration the surface roughness of work piece increases with increasing the cutting tool overhang.

7-The effect of cutting tool vibration in feed direction could be neglect, if compared with that in vertical direction.

7- References

1. Thomas L. Lagö, Sven Olsson, Lars Håkansson and Ingvar Claesson., "Performance of a Chatter Control System For Turning and Boring Applications", 4th GRACM Congress on Computational Mechanics, GRACM., Patras 27-29 June, PP. 3-4. (2002).

2. Luke H. Huang, Joseph C. Chen., "A Multiple Regression Model to Predict In-Process Surface Roughness in Turning Operation Via Accelerometer", Journal of Industrial Technology, "Internet" (www.nait.org)., Vol. 17, No.2, PP. 2-7. (2001).

3. Tamas Kalmar-Nagy, Jon R. Pratt., "Experimental and Analytical Investigation of The Subcritical Instability in Metal Cutting", 17th ASME Biennial Conference on Mechanical Vibration and Noise,

September 12-15, Las Vegas, Nevada, USA. (1999).
4. Joseph C. Chen, Luke H. Huang, Ms. Ashley X. Lan, and Mr. Samson Lee., “Analysis of an Effective Sensing Location for an In-Process Surface Recognition System in Turning Operations ” , Journal of Industrial Technology ,"Internet" (www.nait.org)., Vol. 15, No.3, PP. 2-6. (1999).
5. Thomas M., Beauchamp Y., Youssef A. Y., Masounave J., “Effect of Tool Vibration on Surface Roughness During Lathe Dry Turning Process”, Computers and Industrial Engineering, Elsevier., Vol. 31, No.3, PP. 637-644. (1995).
6. Risbood K. A., Dixit U. S., A. D. Sahasrabudhe., “Prediction of Surface Roughness and Dimensional Deviation by Measuring Cutting Forces and Vibrations in Turning Process”, Journal of Materials Processing Technology, Elsevier., Vol. 132, No.1, PP. 203-214. (2003).
7. Abouelatta O. B., Madl J.., “Surface Roughness Prediction Based on Cutting Parameters and Tool Vibrations in Turning Operations”, Journal of Materials Processing Technology, Elsevier., Vol. 118, No.1, PP. 269-277. (2001).
8. Tim Gutowski., “Machining Processes”, Manufacturing Engineering And Technology, PP. 5-10, (2003) “Internet”, (www.nap.edu/books /0309051924/html/R1.html)
9. Thomas Childs, Katsuhiro Maekawa, Toshiyuki Obikawa and Yasuo Yamane, “Metal Machining”, 1st ed., John Willy and Sons Inc., PP. 101, 136, 281. (2000).
10. Trent E. M., Dmet, Fim, “Metal Cutting”, 2nd ed., Butter worth’s and Co (Publishers) Ltd., PP. 5, 12. (1984).
11. Serope Kalpakjian, and Steven R. Schmid, “Manufacturing Engineering and Technology”, 4th ed., Pearson Education, Inc., PP. 534-539, 694-698, 869-880. (2002).
12. Keraita J. N., Oyango H. J. and Misoi G. K., “Lathe Stability Charts Via Acoustic Emission Monitering”, African Journal of Science and Technology (AJST), Science and Engineering Series., Vol. 2, No.2, PP. 81-93. (2001).
13. Jaton Nakia Wince, “Modeling Chip Formation in Orthogonal Metal Cutting Using Finite Element Analysis ”, Msc. Thesis, Dep. of Mech. Eng., The Mississippi State University., PP. 11-12, 69. (2002).
14. Francis C. Moon and Tamas Kalmar-Nagy., “Nonlineer Models For Comlex Dynamics in Cutting Materials”, Phil. Trans. R. Soc. Lond. A., The Royal Society., Vol. 359, No.1, PP. 695-711. (2001).
15. Arshinov V., Alekseev G., “Metal Cutting Theory and Cutting Tool Design”, 2nd ed., Mir publishers, Moskow, PP. 15, 89-91. (1973).
16. J Lipski., Litak G., Rusinek R., Zaleski K. Szabelski A. Tester, Warminski J. and Zaleski K., “Surface Quality of a Work Material Influence on Vibrations in a Cutting Process”, Journal of Sound and Vibration, Technical University of Lublin Nadbystrzycka, Poland., (2001).

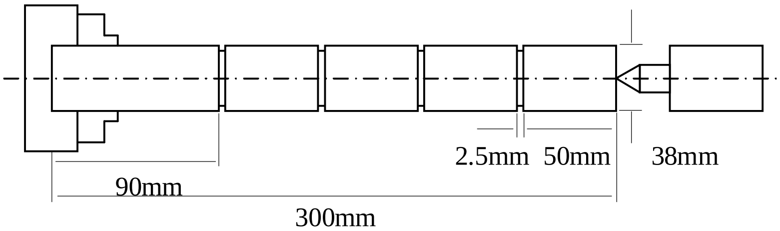
“Internet”,(http://arxiv.org/abs/nlin.cd/0 112044).

Table (1) The levels of the independent variables for the procedure

Variables	Symbol	Units	Level			
			1	2	3	4
Cutting speed	N	Rpm	270	560	1030	
Feed rate	f	mm/rev	0.07	0.13	0.17	
Depth of cut	dp	mm	0.1	0.2		
Tool length	l	mm	25	30	35	40
Approach angle	θ	o˚	75			
Work piece length	L	mm	300			
Work piece diameter	D	mm	40			

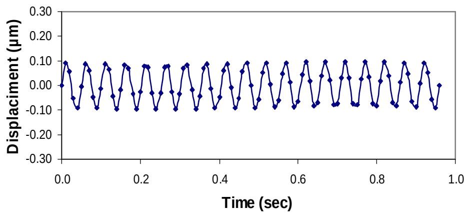
Table(2) The cutting conditions and the groups of experimental testing.

condition	Speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Tool overhang (mm)	Approch angle (degreeº)	Work piece length	Work piece diameter (mm)
A	34	0.07	0.1, 0..2	25, 30, 35, 40	75	300	38
B	34	0.13	0.1, 0..2	25, 30, 35, 40	75	300	38
C	34	0.17	0.1, 0..2	25, 30, 35, 40	75	300	38
D	70	0.07	0.1, 0..2	25, 30, 35, 40	75	300	38
E	70	0.13	0.1, 0..2	25, 30, 35, 40	75	300	38
F	70	0.17	0.1, 0..2	25, 30, 35, 40	75	300	38
G	130	0.07	0.1, 0..2	25, 30, 35, 40	75	300	38
H	130	0.13	0.1, 0..2	25, 30, 35, 40	75	300	38
I	130	0.17	0.1, 0..2	25, 30, 35, 40	75	300	38

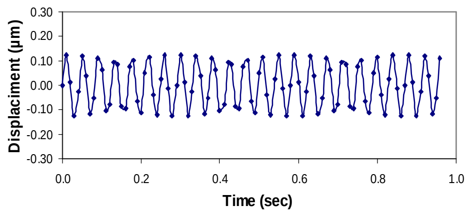


All undercuts = 50mm Starting Diameter = 40mm

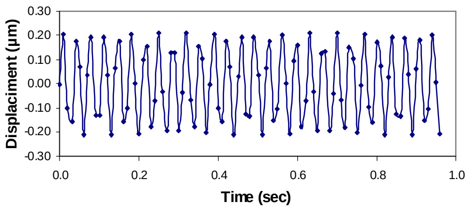
Figure (1) work piece dimensions



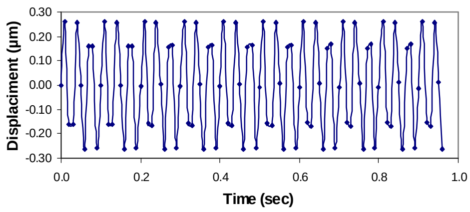
tool overhang = 25mm



tool overhang = 30mm



tool overhang = 35mm



tool overhang = 40mm

Figure (2) frequency responses with time at different tool

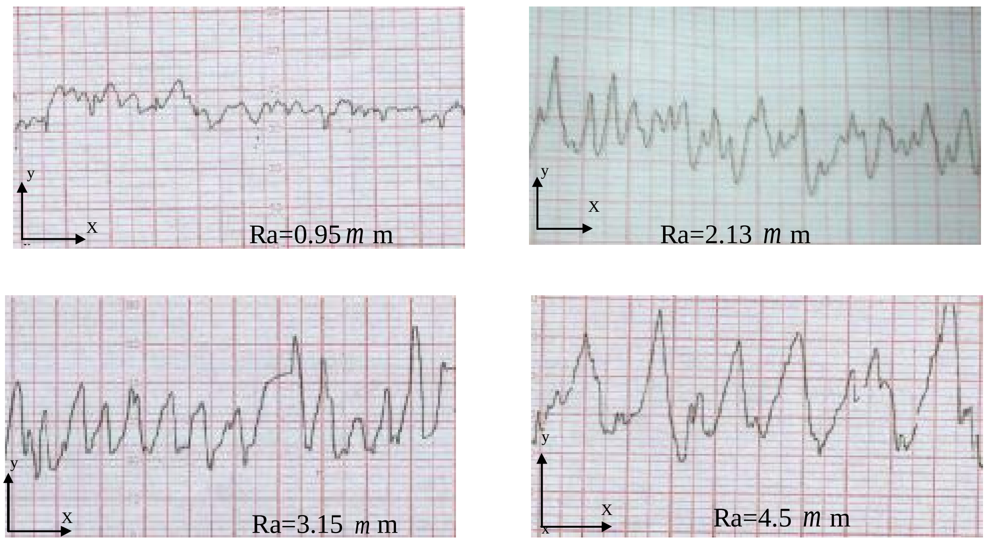


Figure (3) Surface roughness texture at different tool

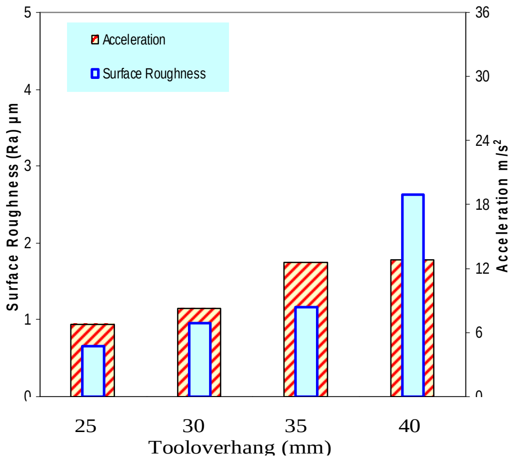


Figure (4-a) Effect of tool overhang on acceleration and surface roughness of work piece for cutting condition (A*)*

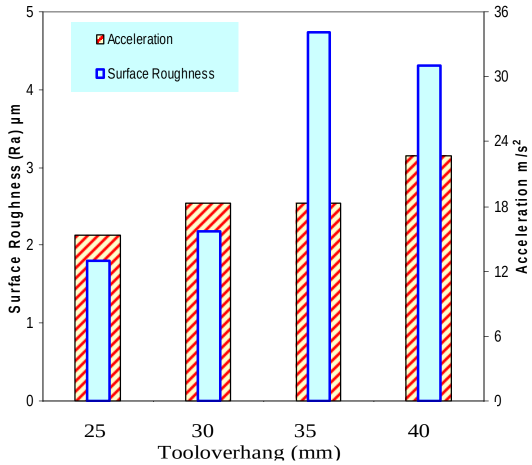


Figure (4-bE effect of tool overhang on acceleration and surface roughness of work piece for cutting condition (***B)***

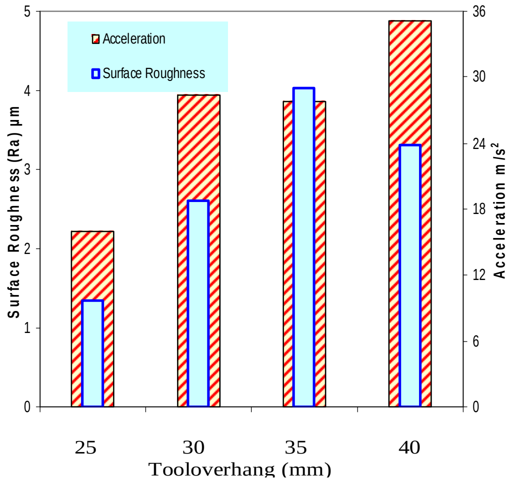


Figure (4-c) Effect of tool overhang on acceleration and surface roughness of work piece for cutting condition (C)

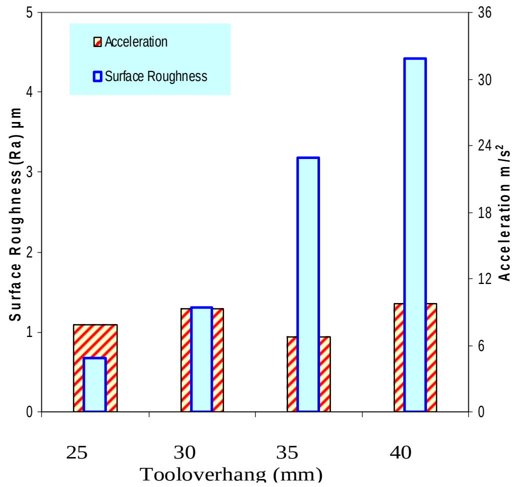


Figure (4-d) Effect of tool overhang on acceleration and surface roughness of work piece for cutting condition (D)

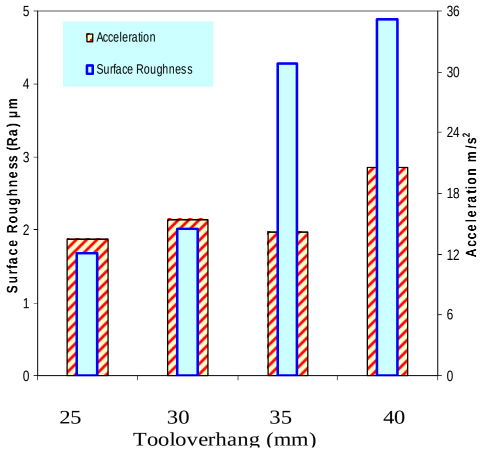


Figure (4-e) Effect of tool overhang on acceleration and surface roughness of work piece for cutting condition (E)

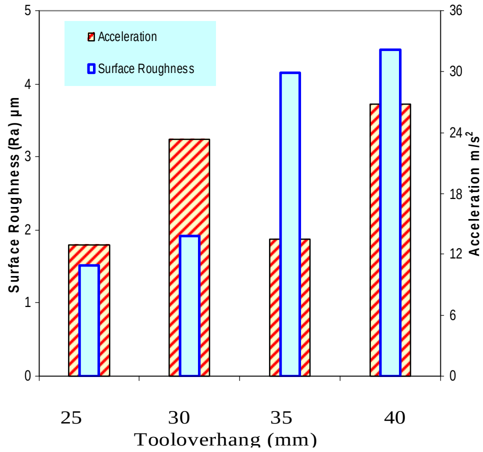


Figure (4-f) Effect of tool overhang on acceleration and surface roughness of work piece for cutting condition (F)

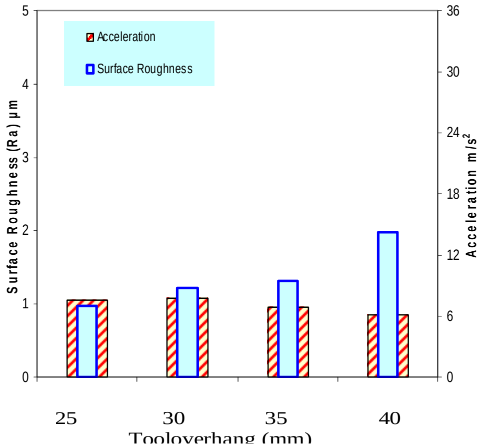


Figure (4-g) Effect of tool overhang on acceleration and surface roughness of work piece for cutting condition (G)

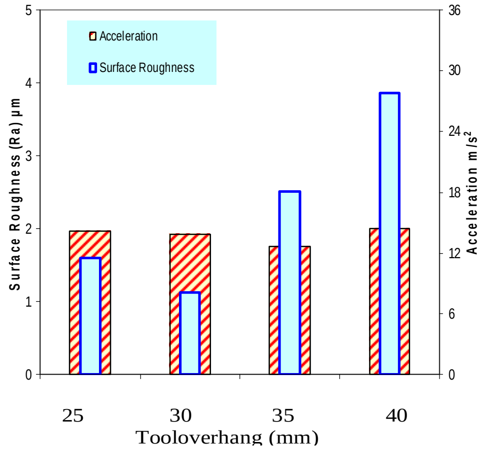


Figure (4-h) Effect of tool overhang on acceleration and surface roughness of work piece for cutting condition (H)

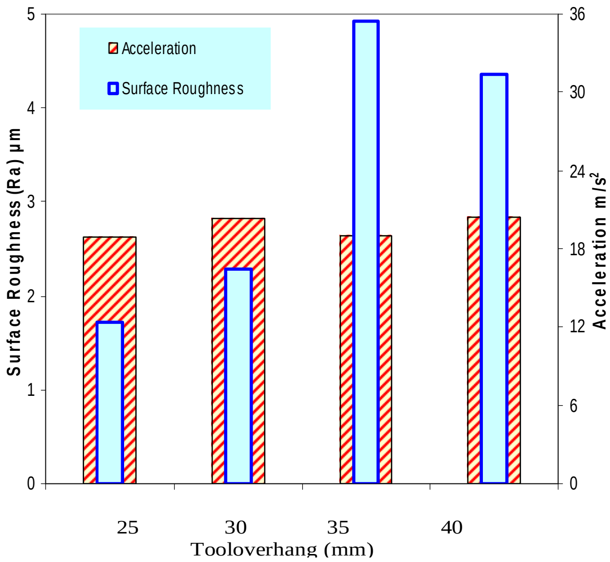


Figure (4-i) Effect of tool overhang on acceleration and surface roughness of work piece for cutting condition (I)