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Reduction of Chatter in Turning by Using A Tool Holder with High Damping Coefficient

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ABSTRACT
Machining of metals is generally accompanied by an intense relative vibration between tool and work, known as chatter. Chatter is unwanted because of its many adverse effects during machining. This paper presents a new method of chatter suppression during turning operation of stainless steel - AISI 201 using tool holders with high damping coefficient. Turning operation of the given work material was conducted using a medium carbon steel tool holder along with two fabricated tool holders made of two types of gray cast iron. Response Surface Methodology (RSM) was used for the design of this experiment. Simulations of total deformation, modal and harmonic response analyses of the tool holders were conducted using ANSYS. Fast Fourier Transform (FFT) was later used to transform the vibration data to a function in frequency domain. The experiments focused on monitoring the surface roughness, sound level and analysis of chips formed during metal cutting. It was observed that both the gray cast iron tool holders contributed to reduction of chatter amplitudes but the annealed gray cast iron tool holder contributed most to the improvement of surface finish and reduction of noise level.

Keywords:Chatter, Gray Cast Iron, Stainless steel, Surface roughness, Sound Level.

1. Introduction
Chatter is an unusual tool behavior and is one of the most critical problems in machining processes. Chatter is unwanted because of its adverse effects on machining accuracy, product quality, operation cost, tool life, and productivity. It must be avoided in order to improve the dimensional accuracy and surface quality ofthe product [1]. Chatter phenomenon was first observed by Taylor [2] during metal cutting. He stated that element chip formation is responsible for chatter. Wiercigrocch et al. [3] stated that the mode coupling resulted when the vibrationin the thrust force direction generated oscillations in the thrust and cutting force directions.Tobias et al. [4] mentioned about the regenerative effect which occurs with single-edged tools, such as lathe tools, when the cutting edge of the tool traverses a wavy surface on the work generated by the previous cut.Experimental works of Eliasberg [5] and Amin [6] showed some contradiction with the regenerative chatter theory.Patwariet al. [7] found that the root cause of chatter was in the coincidence of the frequency of theinstability of chip formation with one of the natural mode frequencies of the machine-spindle-toolsystem during end milling operations. Several researchers have tried to address the chatterphenomenon.In this study, the influence of tool holders with high damping coefficient in suppressing chatter in turning operations on stainless steel - AISI 201 using coated WC-Co insert was investigated.It has been observed that tool holders with high damping coefficient did reduce the chatter vibration and improve the surface finish**.**

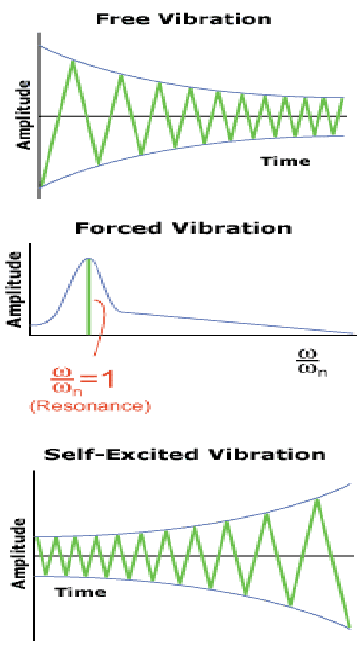

Fig. 1 Types of chatter vibration

2. Experimental Details
Experimental machining was conducted on Engine Lathe Machine, model: CS6266B powered by a 7.5KW motor with a maximum spindle speed of 1600 rpm. Machining was done using three tool holdershaving different materials and properties i.e. carbon steel, pearlitic gray cast iron and annealed gray cast iron. Both the gray cast iron tool holders were fabricated from pearlitic gray iron. One of them was later annealed using a furnace. Fig.2 displaysschematic diagram of temperature distribution for annealing process of the gray cast iron tool holder.

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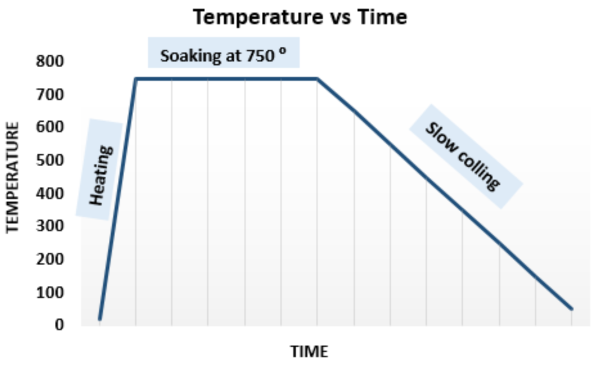


Fig. 2 Temperature vs. time curve in the annealing process of the gray cast iron tool holder

The specimen has been heated for about 2 hours at 750^0 C and then it was slowly cooled to the room temperature.Fig.3 shows the tool holder inside the furnace at 750°C

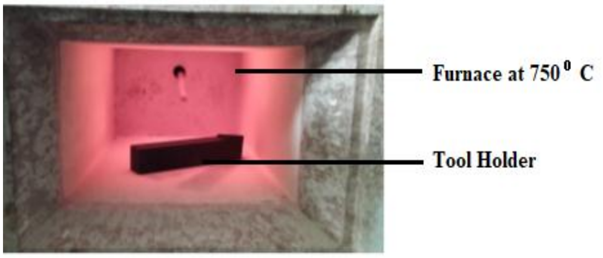


Fig. 3 Gray cast iron tool holder inside the furnace

There were 45 machining runs and these were taken using six coated WC-Co inserts (dimension 1.2mm X 1.2mm). Each cutting edge was used for two consecutive runs.A microphone was used for monitoring the vibrations, which was later investigated using Fast Fourier transformation. A sound level meter was also used for further verification of the accuracy of this method. Fig.2 displays the schematic diagram and photograph of the experimental setup.

Fig.4 Experimental set up for turning operation

Central Composite Design (CCD) of Response Surface Methodology (RSM) was used for the design of experiments (DOE) and Design Expert software version 11.0 was used for this purpose.CCD can run sequentially, it naturally gives severance of two subsets of points where the first subset estimates the linear and two factor interaction effects while the second subset estimates curvatures effects. The second subset need not be run when the data is analysed from the first subset points indicates the absence of significant curvature effects.RSM discovers a relationships between several descriptive variables and one or more response variables. In this project RSM has been used to develop the relation between cutting parameters and responses, which were surface roughness and sound level. The design structure is shown in Table 1 along with the results on surface roughness.

3. Results and Discussions

Surface roughness of three different tool holders has been measured by using a contact type Phase II SRG-4500. Fig. 6 shows the surface roughness tester equipment. Table 1, below, compares the resultant surface roughness for the three cases. It also shows the percentage reduction of those cases.

Fig. 5 Surface roughness tester

Table 1: Comparison of surface roughness for the three cases

Run	Cutting speed (m/min)	Feed (mm/min)	Depth of Cut (mm)	Surface roughness, Ra (µm)			Percentage Reduction (%)
				Carbon Steel	Pearlitic Gray Cast Iron	Annealed Gray Cast Iron	
1	108.07	0.3	1	2.482	2.244	2.162	12.89%
2	141.37	0.49	0.5	3.95	3.63	3.067	22.35%
3	168.86	0.3	1	3.95	3.339	2.12	46.33%
4	108.07	0.09	1	1.077	0.815	0.756	29.81%
5	108.07	0.3	1	3.303	2.484	1.965	40.51%
6	108.07	0.3	1	2.524	2.229	1.64	35.02%
7	108.07	0.3	1	2.221	2.14	1.22	45.07%
8	54.03	0.1	0.5	0.821	0.564	0.562	31.55%
9	29.68	0.3	1	3.185	1.8	1.46	54.16%
10	108.07	0.3	0.29	3.001	2.177	2.056	31.49%
11	108.07	0.58	1	5.442	4.831	3.11	42.85%
12	108.07	0.3	1	2.327	2.073	2.03	12.76%
13	141.37	0.1	1.5	1.351	0.937	0.672	50.26%
14	108.07	0.3	1.7	4.62	2.662	2.48	46.32%
15	54.03	0.49	1.5	5.756	3.948	3.111	45.95%

From Table 1, it can be observed that with the use of annealed gray cast iron tool holder surface roughness improves remarkably. Surface roughness is also dependent on the cutting parameters. From table 1, the highest percentage reduction for roughness was observed when cutting the work material at 29.68 m/min speed, 0.3 mm/rev feed, and 1 mm depth of cut (run number 09) and the effect of different tool holder material on surface roughness (Ra) is shown on Figure 6. The corresponding surface roughness reduction percentage was about 54.16%. This is followed by run number 13 (cutting speed 141.37 m/min speed, feed 0.10 mm/tooth, and depth of cut 1.5 mm) where the reduction is roughly 50.26%. These reductions observed in surface roughness were caused by the damping characteristics of the materials on oscillatory motion of the tool.

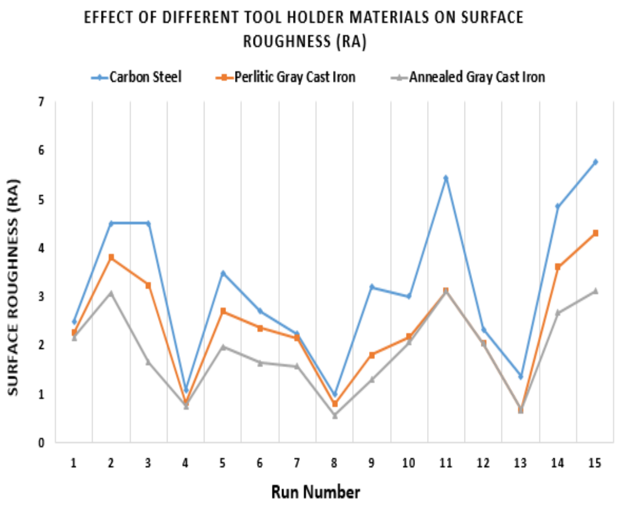


Fig. 6 Influence of different tool holder materials on surface roughness

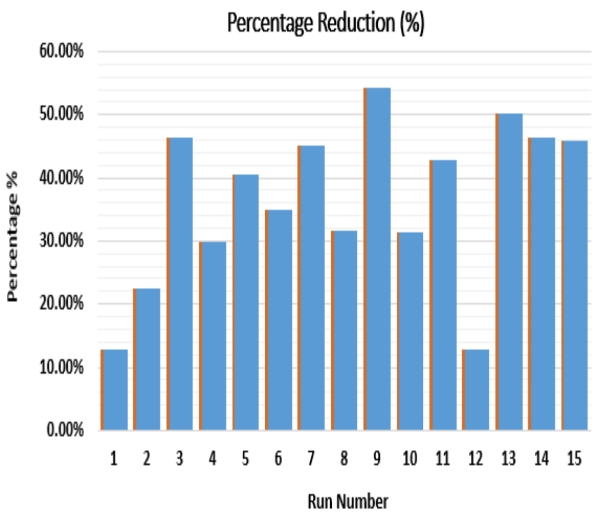


Fig. 7 Percentage reduction of surface roughness due to the change of tool holder materials

The chip reduction coefficient was calculated for the three tool holder materials. The value of the chip reduction coefficient was lower when annealed gray cast iron tool holder was used.

Table 2 Chip Reduction Coefficient of three different tool holder materials.

Run	Chip Reduction Coefficient (ζ)		
	Carbon Steel	Pearlitic Gray Cast Iron	Annealed Gray Cast Iron
1	1.42	1.48	1.35
2	1.17	1.13	1.08
3	1.49	1.38	1.32
4	1.48	1.29	1.18
5	1.46	1.38	1.10
6	1.49	1.41	1.35
7	1.46	1.42	1.39
8	1.35	1.33	1.29
9	1.49	1.42	1.30
10	1.12	1.08	1.02
11	1.43	1.41	1.38
12	1.38	1.32	1.20
13	1.49	1.40	1.20
14	1.37	1.35	1.10
15	1.45	1.42	1.27

Figure 8 shows the graphical comparison chip reduction coefficient of three different tool holder materials

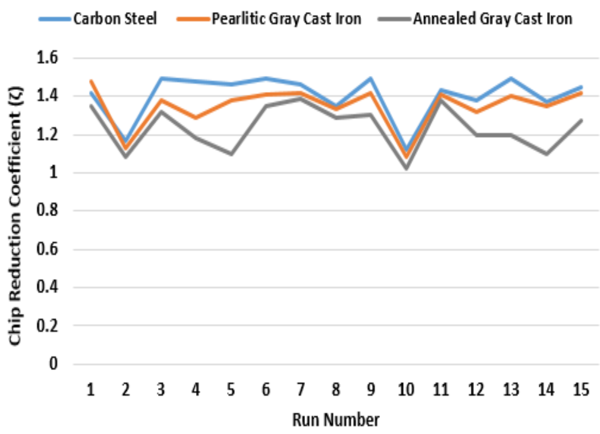
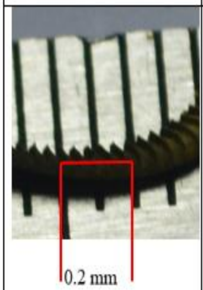
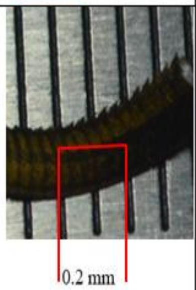
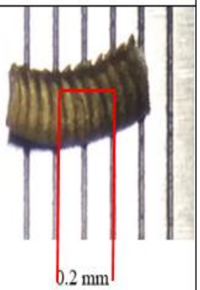


Fig. 8 Comparison of chip reduction coefficient of three different tool holder materials

3.1 Chip Morphology

The effect of different cutting parameters on chip serration frequencies and its interaction with the mode frequencies of the lathe components has been investigated, considering the vibration data that are recorded during machining using a microphone and a sound level meter. The detail calculation for the (09 number run) procedure is shown in Table 3 below.

Table 3 Chip serration frequency calculation for 09 number run

Carbon Steel	Pearlitic Gray Cast Iron	Annealed Gray Cast Iron
		
Cutting Speed(V)=29.289m/min No of serrated teeth(n) = 5 Length = 0.02mm Chip shrinkage coefficient (K) = 1.49	Cutting Speed(V)=29.289m/min No of serrated teeth(n) = 7 Length in = 0.02mm Chip shrinkage coefficient (K) = 1.42	Cutting Speed(V)=29.289m/min No of serrated teeth(n) = 6 Length in = 0.02mm Chip shrinkage coefficient (K) = 1.30
Determination of chip serration frequency		
$fc=\frac{29.289*1000*5}{60(0.2*1.49)}=8191$	$fc=\frac{29.289*1000*7}{60(0.2*1.42)}=10313$	$fc=\frac{29.289*1000*6}{60(0.2*1.30)}=11265$

3.2 Analysis of sound level
The analysis the sound levels of each run of three different tool holder, are shown on the following Table 4.

Table 4 Compression of sound levels of three different tool holder materials

Run	Carbon Steel (dB)	Pearlitic Gray Cast Iron (dB)	Annealed Gray Cast Iron (dB)	Percentage Reduction (%)
1	94.3	93.6	90.8	4%
2	99.3	93.3	92.3	7%
3	95.7	94	90.4	6%
4	91	87.2	85.7	6%
5	94.9	91.6	89.6	6%
6	95	93.4	89.1	6%
7	94.2	93.5	89.6	5%
8	85.2	84.2	83.8	2%
9	84.3	80.5	77.9	8%
10	88.1	87.3	86.6	2%
11	98.8	97.4	89.1	10%
12	95.7	94.7	91	5%
13	94.1	89.9	87.4	7%
14	97.9	97.8	95.9	2%
15	104.6	99.6	97.3	7%

Figure 9 shows the graphical comparison of sound level of three different tool holder materials

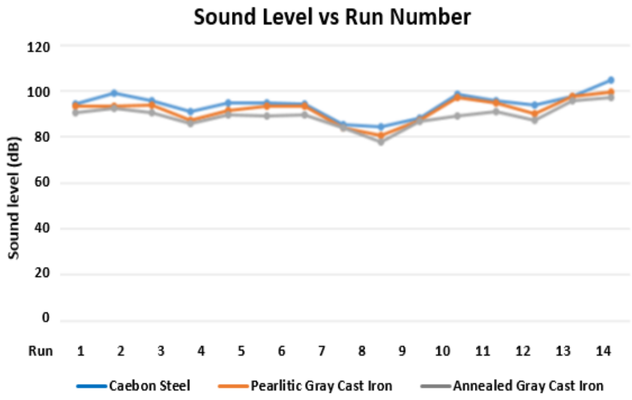


Fig. 9 Comparison of sound level of three different tool holder materials

So from the graph it is clear that for annealed gray cast iron, minimum sound level is found. For further verification, FFT function was done. After plotting amplitude Vs frequency bins graphs with the help of FFT the highest peak value of the amplitude of each run was selected for measuring the sound level for three different tool holders.Figure 10 shows the Fast Fourier transformation for run number 09.

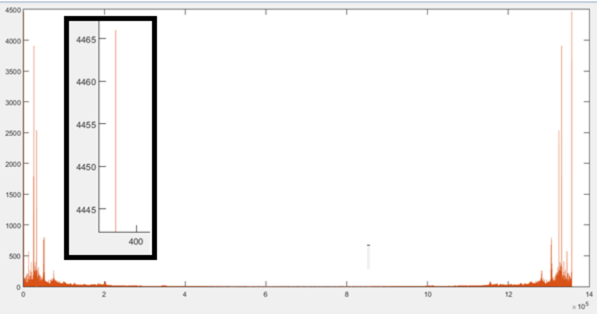


Fig. 10 FFT (Fast Fourier transformation) and maximum peak point of amplitude vs frequency bin for run number 09

4.Conclusions
The following specific conclusions were drawn from the research results:

1. The change of tool holder material to annealed gray cast iron resulted in a maximum reduction of 54% in average surface roughness; the average reduction being 36.49%. This significant improvement in surface finish would likely eliminate the cost of operations for grinding and polishing in machining of AISI 201.
2. Both primary and secondary serrated teeth were formed in turning of AISI 201 work material using coated WC-Co.
3. The chips were more stable when Annealed gray cast iron tool holder was used and the chip serration frequencies are higher than the other two. This phenomenon occurred because of the greater damping effect of the annealed gray cast iron tool holder.

5. Recommendations

[1] Scanning Electron Microscope (SEM) could be used for further analysis of the chips and tool wear.
[2] To conduct the experiments using data acquisition system i.e. accelerometer for measuring frequency and amplitude accurately.
[3] CNC lathe machine is recommended to be used for getting more accurate results.

NOMENCLATURE

fc : frequency of the serrated teeth formation, Hz
L :length of the portion of the chip, mm
K : coefficient of chip shrinkage
V : cutting speed, m/min
n : number of serrated teeth

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