EFFECT OF ANNEALING ON MACHINABILITY OF GREY CAST IRON

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ABSTRACT

This study investigates the influence of process parameter on machined cast iron under varying material strength and cutting conditions. The three process parameters considered in this study are spindle speed (75-135 rpm), feed rate (0.05-0.4 mm/min) and depth of cut (0.01-0.08 mm). The cast iron bars wereannealed and machined under wet and dry cutting conditions. Taguchi design of Minitab 18 was employed to optimize and analyze results. The signal-to-noise (S/N) ratio was used to analyze results generated, identify optimal process parameters (factors) and analyze the effect of these parameters on tool-tip temperature. Results shows that the spindle speed was the most significant factor affecting tool-tip temperature reduction, followed by feed rate, while the depth of cut has least role to play on tool-tip temperature. Depth of cut and spindle speed both significantly influenced increment in material removal rate. The annealed cast iron bar had a better surface integrity than the unannealed sample bars. Conclusively, the preferred condition for machining grey cast iron bar was annealed and wet machining condition.

KEYWORDS*: Cast iron; turning; tool-tip temperature; material removal rate; surface roughness*

1.0 INTRODUCTION

Cast irons are one of the materials mostly used by the industries not only because of its inherent characteristics but also its immense versatility (Dawson, 2004). It finds application in a wide range of sectors such as production of pipes, machines and automotive industry parts, like cylinder heads. It is used in the culinary field for pots, pans and all sorts of utensils that are

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used for heating purposes (José et al., 2017). Though various types of cast iron exist, grey cast irons (alloys of iron, carbon and silicon) typically contain from 1.7% - 4.5% carbon and 1% - 3% silicon as major constituents (Herring, 2004). Heat treatment helps improve machinability of materials by extending the consistency and range ofproperties of a metal such as cast iron (Verdeja, 2009). An improvement in Surface Roughness will ensure the production of parts with better surface integrity and a reduction in part failure. Numerous researchers have studied the behavior of cast iron when machined under various conditions and have reported their results. Nwosu and Chinwuko (2013), investigated the characteristic behavior of cast iron, aluminum and brass under the effects of cutting speeds and feed rates in cylindrical machining operation. They reported an increase in cutting force with increased feed rate implying that machinability decreased with feed rate in the order aluminum, brass and cast iron. Maksudul et al. (2015), studied the effect of optimization of material removal rate for ASTM A48 grey cast iron in turning operation. Their studied adopted spindle sped, feed rate & depth of cut as cutting parameters, while a HSS (High Speed Steel) was used as cutting tool. They concluded that spindle speed had the most significant contribution on the metal removal rate among all the three parameters. Guesser et al. (2016), discussed the surface changes during turning of grey cast iron. They reported a presence of pores on the machined surfaces of the cast iron affecting the integrity of the material for use. José et al. (2017), performed a review on the machining of cast iron. They discussed the characteristics, properties and machinability of cast iron, the also covered the main output parameters in machinability. Generally, poor surface profile and reduced tool life are the major problems with machining grey cast iron. This study is therefore an attempt to improve the machinability of grey cast iron via heat treating (annealing) and application of cutting fluid during machining. It is significant because its goal is to analyze the effect of heat treatment on surface profile improvement.

2.0 MATERIALS AND METHODS

A cast iron bar was acquired for this research from Ibadan, Oyo State Nigeria. The cast iron material had a length of 1,000 mm with a cuboid like geometry. It has a height of 25 mm and a breadth of 30 mm. The material was then machined into 4 cylindrical parts with a length of 110 mm each and diameters ranging from 20.5 mm to 20.0 mm for the purpose of the experiment. Figure 1 and 2 shows the cast iron bars before and after preparation respectively.

Figure 1 Cast iron bars before preparation

Figure 2 Cast iron bars after preparation

The cutting fluid used for this experiment was soluble oil. The soluble oil was mixed with water to give a milky appearance (emulsion) with a water-oil ratio of 80 – 20 %. A psychochemical analysis of the cutting fluid was done to determine the chemical composition of the cutting fluid. Figure 3 and Table 1 shows the high speed steel and cutting fluid used for the study and physicochemical analysis results.

A lathe machine in Figure 4, Colchester mastiff 1400 was used during this study. This machine has the ability to perform various operations, such as cutting, knurling, drilling, turning, etc. The lathe machine was used to machine the annealed cast iron using the turning operational feature of the machine. High speed steel (HSS), AISI M-42 type with the following geometry: nose radius of 0.5 mm, back rake angle of 6˚, side rake of 10˚, end cutting edge of 12˚ and side cutting edge of 12˚. Is intended to be used in the experiment.

Table 1 Physicochemical analysis of soluble oil

Properties analyzed	Soluble oil	Mixed soluble oil
PH value	7.1	6.8
Saponification (mgKOHg^{-}1)	79	85
Acid value (mgKOHg^{-}1)	6.2	5.5
Density(g)	41.34	42.65
Flash point (°C)	114	80

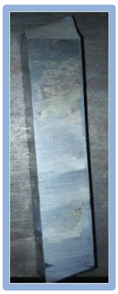


Figure 3 High speed steel

Figure 4 Colchester Mastiff 1400 Lathe Machine

Brother furnace XD-1200N was the industrial furnace in Figure 5 was used to anneal the cast iron, it annealed the cast iron at a temperature of 800°C for time duration of 1hour and was thereafter furnace cooled. Surface Profile Gauge SRT-6223 in Figure 6 was used at the end of the experiment to determine the surface roughness of the annealed cast iron materials after it was machined.

Figure 5 Brother furnace Xd-1200n

Figure 6 Surface profile gauge

A temperature data logger, also called temperature monitor, is a portable measurement instrument that is capable of autonomously recording temperature over a defined period of time. The temperature data logger was used to measure the heat generated while the machining process took place. Data was captured by Logger by attaching thermocouple wire at a separation of 5 mm from the cutting tip. Cammry weighing balance with maximum weight of 40 kg and minimum of 200 g was used to measure the weight of the workpiece material before and after each experimental run, this was done to determine the material removal.

The work piece was divided into four labeled A-D. Sample A and B were annealed and the other two samples were left unannealed. The Design of experiment was done using Taguchi method with an orthogonal array as shown in Table 2 generated for the runs using spindle speed, feed rate and depth of cut as cutting parameters.

Table 2 Orthogonal array showing process parameters

RUN	**SPEED (rpm)**	**FEED (*mm/min*)**	**DOC (mm)**
1	75	0.05	0.01
2	75	0.1	0.05
3	75	0.4	0.08
4	100	0.05	0.01
5	100	0.1	0.05
6	100	0.4	0.08
7	135	0.05	0.01
8	135	0.1	0.05
9	135	0.4	0.08

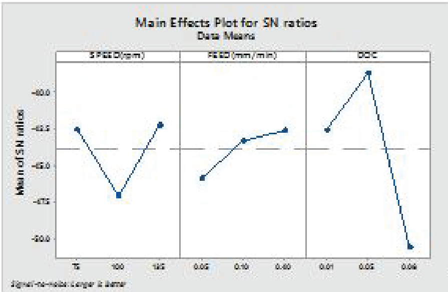
The turning of both annealed and unannealed cast iron was performed at three different spindle speeds of 75 rpm, 100 rpm and 135 rpm. The feed rates at each spindle speed were 0.05, 0.1 and 0.4 mm/min. The depths of cut used for turning at each one of the spindlespeedwere 0.01, 0.05, and 0.08 mm. The tool-tip temperature was measured using Temperature Data Logger by attaching thermocouple wire at a separation of 5mm from the forefront of the device. After every run, the weight of the sample was confirmed and this was used to determine the material removal rate (MRR). MRR was calculated using an equation (1) proposed by (Das et al., 2012). The Surface roughness of the samples was obtained by the use of a profilometer, as given in Equation (1) as follows:-

$$MRR = \frac{Volume\ Removed}{Cutting\ Time} \quad (1)$$

Two of the four samples, one annealed and the other not annealed went through this process with the use of soluble oil as cutting fluid and the remaining two samples, one also annealed and the other not annealed went through the machining process without the use of any cutting fluids.

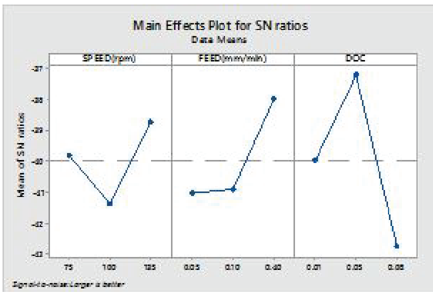
3.0 RESULTS AND DISCUSSION

The results were analyzed using signal-to-noise (S/N) ratio. A total of nine (9) runs were carried out at different speed and comparisons of values were carried out using the table below. In this experiment, Smaller-is-better S/N ratio was chosen for Surface roughness (SR), and larger-is-better S/N ratio was chosen for material removal rate (MRR) and smaller-is-better S/N ratio was chosen for Tool-Tip Temperature. These three scenarios indicated better performance of the process. Figure 7, 8, 9 and 10 shows results from analysis of effect of cutting parameters on the Material removal rate and Tool-Tip temperature for dry and wet machining conditions. This was carried out for results after machining of both the annealed and unannealed samples. Figure 7 and 8 shows that Depth of Cut had the most significant effect on the Material Removal rate during machining of annealed samples. However, where feed rate was the least significant during dry machining of annealed sample, speed was the least significant during wet machining of annealed cast iron. The optimum cutting parameters for larger MRR during dry and wet machining is (S_3:135 rpm, F_3:0.4 mm/min; D_2:0.05 mm).



Level	SPEED(rpm)	FEED(mm/min)	DOC
1	-42.53	-45.89	-42.58
2	-47.09	-43.33	-38.67*
3	-42.22*	-42.62*	-50.59
Delta	4.87	3.27	11.92
Rank	2	3	1

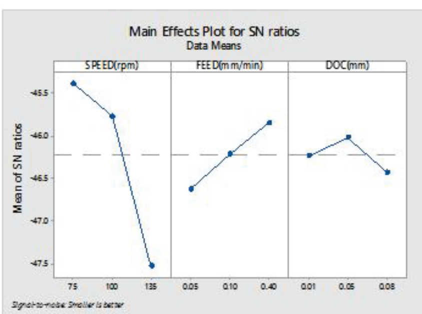
Figure 7 S/N Ratio for MRR dry machining of annealed sample



Level	SPEED(rpm)	FEED(mm/min)	DOC
1	-39.80	-41.02	-39.97
2	-41.37	-40.91	-37.21*
3	-38.73*	-37.98*	-42.74
Delta	2.64	3.04	5.53
Rank	3	2	1

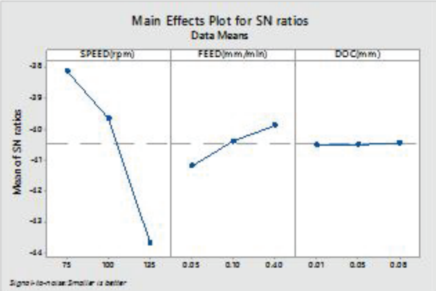
Figure 8 S/N Ratio for MRR for wet machining of annealed sample

Figures 9 and 10 show that cutting speed had the most significant effect on the tool-tip temperature during machining of unannealed samples. Similarly, depth of cut was the least significant during dry and wet machining of the unannealed grey cast iron.



Level	SPEED(rpm)	FEED(mm/min)	DOC(mm)
1	-45.38	-46.62*	-46.24
2	-45.77	-46.22	-46.02
3	-47.53*	-45.84	-46.43*
Delta	2.15	0.78	0.41
Rank	1	2	3

Figure 9 S/N Ratio for tool-tip temperature for dry machining of unannealed sample



Level	SPEED(rpm)	FEED(mm/min)	DOC(mm)
1	-38.12	-41.17*	-40.50*
2	-39.64	-40.38	-40.48
3	-43.66*	-39.87	-40.44
Delta	5.54	1.30	0.06
Rank	1	2	3

Figure 10 S/N ratio for tool-tip temperature for wet machining of unannealed sample

The optimum cutting parameters for larger Tool-Tip temperature during dry and wet machining are (S_3:135 rpm, F_1:0.05 mm/min; D_1:0.8 mm) and (S_3:135 rpm, F_1:0.05 mm/min; D_1:0.01 mm)

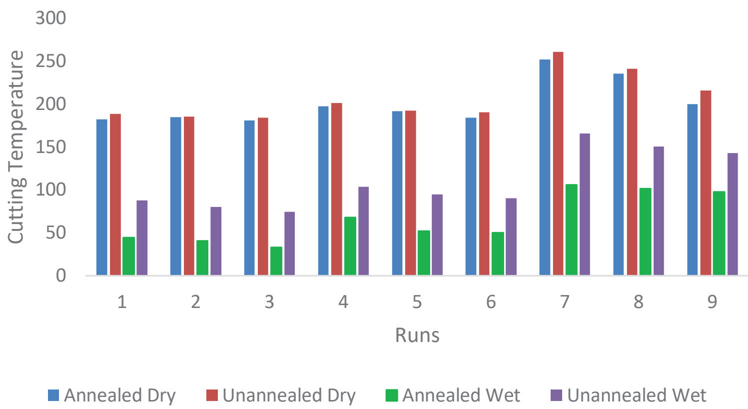
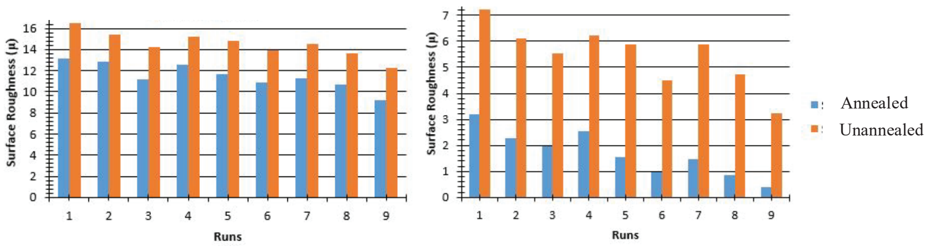


Figure 11 Cutting Temperature for cast iron samples for various machining conditions

Figure 11 shows the cutting temperature during machining of the samples under various conditions. Machining of the annealed sample using soluble oil as cutting fluid reduced the cutting temperature to a low value of 33.1°C (run 3). Figures 12 (a) and (b) shows surface roughness results during dry and wet machining of annealed and unannealed cast iron. The lowest surface roughness value obtained during machining of the unannealed sample was 12.24 µm, this reduced to 9.24 µm for annealed machining resulting in a 24.5% improvement in surface roughness. However, during wet machining, the lowest surface roughness value obtained was 3.22 µm for unannealed cast iron, this as well reduced to 0.41 µm during machining of annealed cast iron. This result shows over 87% improvement in the surface roughness of the annealed cast iron machined wet. Results from Ogedengbe et al. (2017) and Aniza et al.(2012) show similar patterns.



(a) (b)

Figure 12 Surface roughness chart for machining of annealed and unannealed cast iron (a) dry (b) wet

4.0 CONCLUSION

Summarily, this work was an attempt to improve the machinability of grey cast iron using heat treatment and cutting fluids. Results obtained shows that during wet and dry turning of annealed and unannealed cast iron using HSS tool and soluble oil as coolant aided the following conclusions:-

i. Spindle speed and depth of cut had the most significant effect on the material removal rate when turning cast iron with delta values of 11.92, 4.87 and 5.53, 2.64 for dry and wet machining conditions respectively.
ii. Tool-tip temperature reduced during dry machining from 260oC to 183oC and from 165oC to 33.1oC during wet machining by annealing sample bar. Hence, tool-tip temperature was generally lower when machining annealed cast iron.
iii. Surface roughness reduced by 24.5% when sample was annealed before dry machining and by 87% when sample was annealed before wet machining. Hence, surface roughness can be greatly improved when machining grey cast iron after annealing and in wet condition.

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