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Investigation on Effect of Material Compositions on Machinability of Carbon Steels

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Abstract-

Steels are basically classified based on their carbon contents. In view of this, the processing of steels is greatly affected by their composition, particularly their carbon content. This paper reports on the machinability of three different steels with varying carbon contents. The steel samples were sourced from Owode metal market in Ilorin, Kwara State and their percentage compositional analysis was carried out at Universal Steels Limited, Lagos. The steel samples were classified into high, medium and low carbon steels based on their percentage carbon content. The machining condition was wet and the machining parameters used were depth of cut (0.2 – 0.6 mm), feed rate (0.05 – 0.15 mm/rev), and cutting speed (100 - 150 rpm). The experimental runs were designed using Taguchi orthogonal array of Minitab version 16 and the cutting temperature was monitored with a digital thermometer and k-type thermocouple wires. The experimental results were analysed using Minitab 18 with a focus on percentage contribution of various factors affecting surface roughness, chip morphology, cutting temperature and material removal rate. Results show that surface finish is highest in low carbon steel and lowest in high carbon steel. The responses show that machinability of the steel improved with a reduction in carbon content.

Key words: Machinability, Steel, Surface Roughness, Carbon content

1. Introduction

The Steel family is a very vital part of engineering materials because it boasts of the largest practical applications unlike any other engineering materials used in various sectors [1]. Steels are widely used as structural materials because of various desirable properties they possess some of which include, high strength, low cost, good corrosion and wear resistance as well as good magnetic properties [2][3]. Although rolling and casting are some of the methods used previously for steel production, powder metallurgy method has become preferred in recent years [4][5]. Steels have been classified into low, medium and high carbon steels based on amount of carbon content they possess. An increase in the carbon content results in a harder and stronger metal [6][7][2]. [8] investigated the effect of carbon composition on microstructure of steels. Four different bars with carbon composition of between 0.05 and 0.35 wt % were heat treated and their microstructure was examined under optical microscope. Authors reported that as carbon contents increased, elongation to fracture decreased. A survey carried out by [9] on steels showed that the different morphology leads to varying mechanical properties, workability and machinability. Machining steel can be difficult because of the presence of iron carbide, cementite (Fe₃C), or various alloy carbides which causes hardness and wear resistance [10]. [11] reviewed the machining of hardened steel. Experimental investigation on performance modeling and cooling techniques was reviewed. Authors concluded that higher surface roughness was



reported by researchers for hardened steel types. This study was therefore an attempt to investigate the influence of material composition especially carbon content on machinability of steels.

2. Methodology

2.1 Material Sourcing and Preparation

The workpiece materials used for this experiment were 3 carbon steel bars sourced from Owode metal market in Ilorin, Kwara state, Nigeria. The steel bars were pre-machine to a diameter of 20mm and length 160mm each (Figure 1). They were afterwards cleaned to eradicate contaminants, dirt and grease and a chemical compositional analysis of the carbon steels was carried out using an AMATEK spectrometer MAXx LMM05 and the results is as shown in Tables 1, 2 and 3.

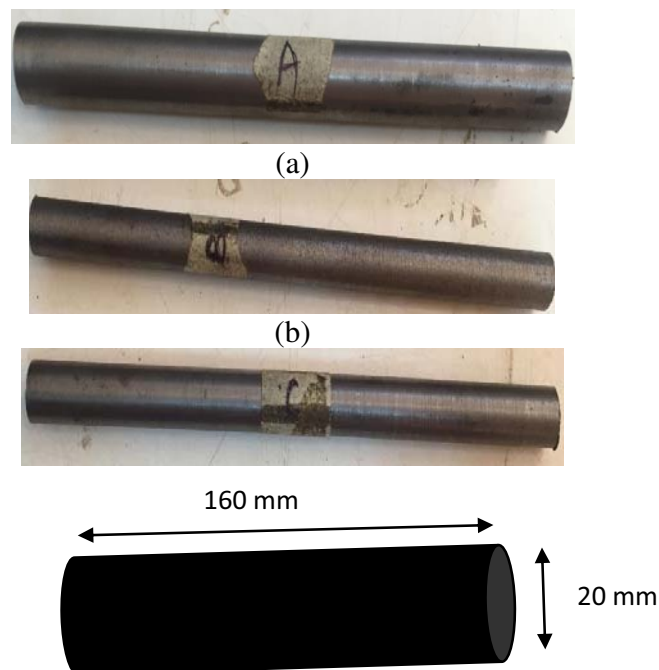


Figure 1: Photo of the Carbon Steels (a) High (b) Medium (c) Low (d) 3D schematic of work pieces

Table 1: Chemical composition of high carbon steel

Element	Fe	Si	Cr	S	P	Mn	C	Ni	Sb	Nb	W	V	Mo	Pb	Cu	T i
% Comp	Bal.	0.510	0.054	0.045	0.032	0.65	0.840	0.024	0.0008	0.0013	0.0032	0.0007	0.022	0.0016	0.060	0.0009

Table 2: Chemical composition of medium carbon steel

Element	Fe	Si	Cr	S	P	Mn	C	Ni	Sb	Al	Co	V	Mo	Pb	Cu	Ti
% Comp	Bal.	0.303	0.0484	0.0246	0.0130	0.678	0.377	0.0399	0.0008	0.0026	0.0122	0.0018	0.0067	0.030	0.0158	0.0008

Table 3: Chemical composition of low carbon steel

Element	Fe	Si	Cr	S	P	Mn	C	Ni	Sb	Al	Co	V	Mo	Pb	Cu	Ti
% Comp	Bal.	0.005	0.082	0.016	0.009	0.211	0.249	0.046	0.0008	0.044	0.0042	0.0007	0.0054	0.0015	0.0147	0.0006

2.2 Hardness Test

The hardness value of the three sample bars was determined using a Vickers hardness tester. The test conditions included the application of a load of 40N for a period of 60secs. The hardness value was thereafter calculated using equation 1;

$$HV = 1.85437 \frac{P}{d^2} \quad (1)$$

Where HV , P and d represent hardness value, applied load and diagonal length of indentation respectively. A total of 5 trials were carried out and the maximum, minimum and average values of Vickers hardness was obtained and recorded.

Table 4: Hardness Value for Carbon Steel (load = 40N)

S/N	Carbon Content (wt %)	Hardness Value (HV)
1	0.249	160
2	0.377	210
3	0.840	280

2.3 Design of Experiment

The experiment was designed using Minitab version 18.0. The significant cutting parameters affecting the machining of steel determined from literature are cutting speed (V), feed rate (f) and depth of cut (d). The level of the factors was based on literature and trial reduction. Taguchi's L_9 (3^3) orthogonal array was used for the experimentation and values were assigned to columns representing cutting speed, feed, and depth of cut, respectively. Tables 5 and 6 shows the process parameters and orthogonal array used for the experimentation.

Table 5: Process parameters for experimentation

Factors	Level	
	Low	High
Cutting Speed (m/min)	100	150
Feed Rate (mm/rev)	0.05	0.15
Depth Of Cut (mm)	0.2	0.6

Table 6: Experimental Orthogonal Array

Run	L ₉ (3 ³)		
	Feed rate mm/rev	Speed m/min	Depth of cut mm
1	0.05	100	0.2
2	0.10	100	0.4
3	0.15	100	0.6
4	0.05	125	0.4
5	0.10	125	0.6
6	0.15	125	0.2
7	0.05	150	0.6
8	0.10	150	0.2
9	0.15	150	0.4

2.4 Cutting Fluids

The machining condition was wet with soluble oil and engine oil used as cutting fluids. The soluble oil was sourced from the market while the spent engine oil was sourced from an automobile technician in Ilorin, Kwara State. The engine oil was a waste product removed from serviced automobiles which was supposed to be disposed. The chemical analysis of the two cutting fluids was carried out and result of the analysis is show in Table 7.

Table 7: Chemical Analysis of Cutting fluids

Property	P. h	Saponificatio n (mgKOHg ⁻¹)	Acid Value (mgKOHg ⁻¹)	Density (g)	Flash Point (°C)	Viscosity (mm ² /sec)
Soluble Oil	7.1	7.9	6.2	41.34	114	46

Spent Engine Oil	7.3	6.7	6.9	52.12	132	65
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2.5 Experimental Procedure

The material was loaded on the conventional lathe machine (SIBIMEX Model 315/103) used for the study. A total of 9 turnings were carried out on each steel bar using both cutting fluids (soluble oil and engine oil) resulting in 54 experimental runs altogether. The experimental cycle and setup for study is as shown in Figures 2 and 3 respectively. The measurement of surface roughness was done with a 2011 model of TR 210 profilometer which has a precision of 0.005-16 μm .



Figure 2: Experimental Cycle for Machining

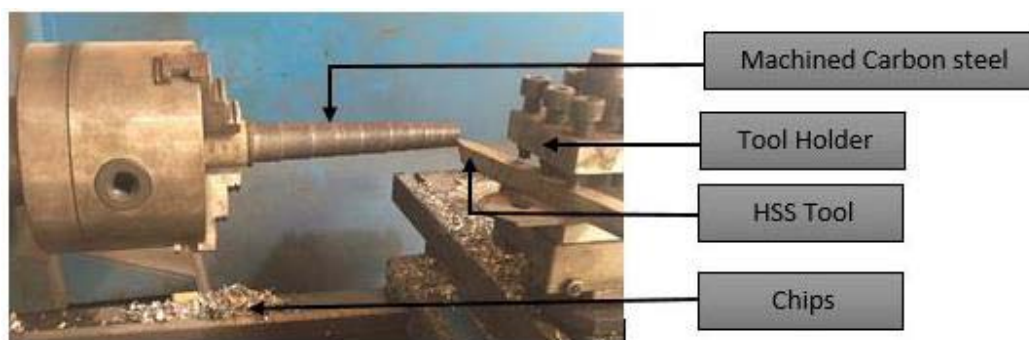


Figure 3: Experimental Set up for Study

2.6 Material Removal Rate (MRR)

The quantity in volume of material removed per time was calculated (Equation 2) and the weight of the workpiece was measured before and after each machining run using a Cammry electronic weighing balance. The machining time was also monitored using a stop watch. This procedure was repeated for all machining trials.

$$\text{Material Removal Rate (MRR)} = \frac{w_1 - w_2}{T} \quad [2]$$

3. Results and Discussion

The effect of material composition on machinability of carbon steels has been investigated. Result from machining was analyzed using the “smaller is better” and “larger is better” options of Signal to Noise Ratio (S/N) in Minitab 18 to determine the effect of machining parameters on the Surface Roughness and Material Removal Rate respectively. Results (Table 8) show that Cutting speed and Feed rate both had the most significant effect on Surface roughness during machining of carbon steel with soluble oil, this result agrees with [12]. The optimum machining parameters as shown in asterisks were V_1 , F_2 and D_1 (i.e. 100m/min, 0.10 mm/rev and 0.1mm). A similar trend was observed during machining of carbon steel using engine oil as cutting fluid. However, Feed rate and Depth of cut had the most significant effect on Material Removal Rate during machining of carbon steel using soluble oil as cutting fluid. A similar pattern was also observed when engine oil was used as cutting fluid while machining carbon steels. [2][9] reported that the use of cutting fluid during machining greatly increased tool life compared to tool life obtained when cutting fluid was not applied under same machining parameters. This was so because hardness value was preserved over a longer period of time during wet machining hence temperature reduction at cutting zone resulted in a preservation of tool and elongation of tool life.

Table 8: S/N ratio for SR and MRR (Soluble Oil)

Factors	Levels				
	1	2	3	Delta	Rank
Surface Roughness					
Cutting Speed (V)	-5.198*	-4.693	-4.312	0.886	1
Feed Rate (F)	-4.771	-4.933*	-4.499	0.435	2
Depth of Cut (D)	-4.814*	-4.680	-4.709	0.134	3
Material Removal Rate					
Cutting Speed (V)	-11.028	-11.543*	-9.338	0.897	3
Feed Rate (F)	-11.084*	-10.187	-10.638	2.205	1
Depth of Cut (D)	-10.716	-10.491	-10.701*	1.225	2

Table 9: S/N ratio for SR and MRR (Spent Engine Oil)

Factors	Levels				
	1	2	3	Delta	Rank
Surface Roughness					
Cutting Speed	-6.643*	-6.632	-6.127	0.781	1

Feed Rate	-6.751	-6.893*	-6.629	0.352	2
Depth of Cut	-6.849	-6.802	-6.111	0.042	3
Material Removal Rate					
Cutting Speed	-12.124	-12.342*	-10.231	0.897	3
Feed Rate	-12.042*	-11.127	-11.718	2.205	1
Depth of Cut	-11.126	-11.811	-11.901*	1.225	2

Figure 4 shows the effect of cutting speed on surface roughness for low, medium and high carbon steels while machining using soluble oil as cutting fluid. Generally, there was a gradual decrease in surface roughness as the cutting speed increased for all the three carbon steel types. However, higher surface roughness values were recorded for high carbon steel compared with both medium and low carbon steels. The higher surface roughness values obtained while machining high carbon steel resulted from the high hardness value of the steel (Table 4). The carbon content in the composition of the steel made the steel harder resulting in higher heat generation as seen in Figure 5, this result shows similar pattern with [1] who reported that with high carbon content there was higher strength for steel. The highest cutting temperature was observed during machining of high carbon steel. Generally, machinability of the low carbon steel was easier compared to machinability of high carbon steel.

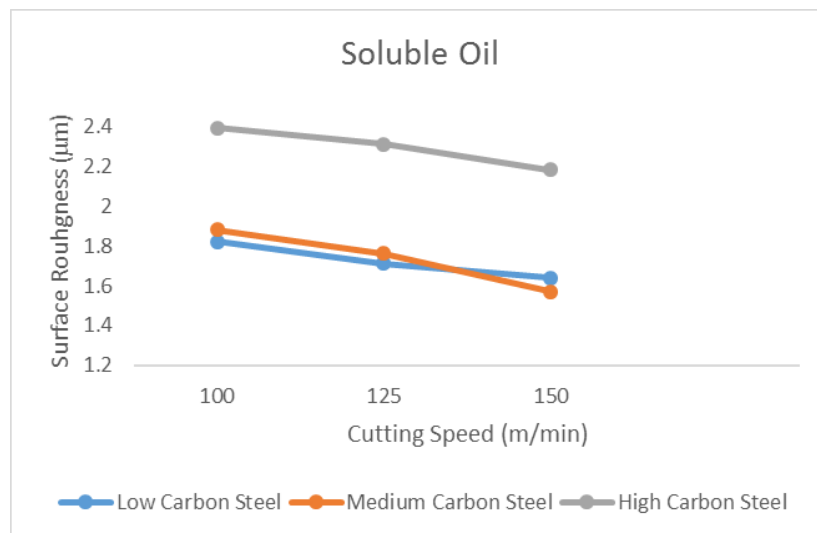


Figure 4: Surface Roughness at various Cutting Speeds (Cutting Fluid: soluble oil)

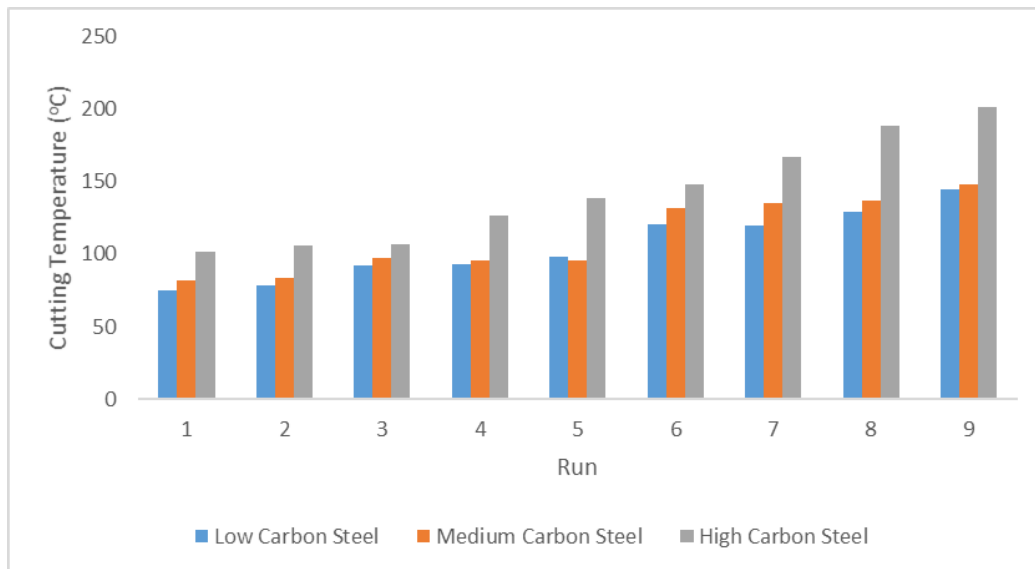


Figure 5: Cutting Temperature during machining with Soluble Oil

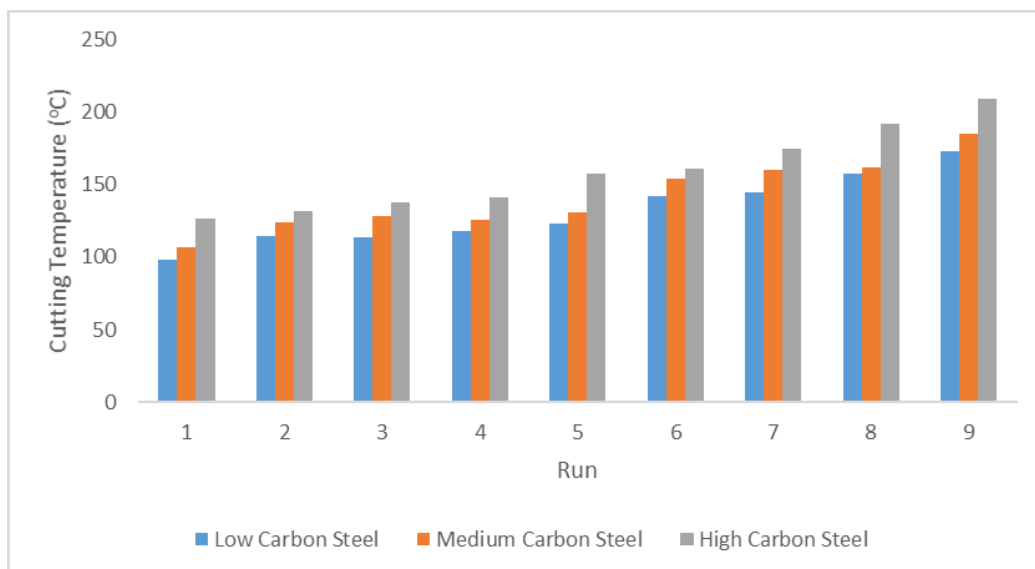


Figure 6: Cutting Temperature during machining with Spent Engine Oil

As shown in Figure 6, a steady rise in cutting temperature was observed when machining with spent engine oil compared with cutting temperature when machining with soluble oil (Figure 5). The increase in temperature signified a superior cooling ability for soluble oil, however, results of surface roughness for soluble oil and spent engine oil while machining the three carbon steel types as shown in Figures 7 and 8 showed better surface roughness values when spent engine oil was used as cutting fluid compared with surface roughness values when soluble oil was used as cutting fluid. As shown in Table 4, spent engine oil had a greater viscosity $65 \text{ mm}^2/\text{sec}$ hence was able to reduce friction between workpiece and tool more efficiently than soluble oil with a

viscosity of 45 mm²/sec. Hence, spent engine oil was preferred as a cutting fluid because of its excellent lubrication ability.

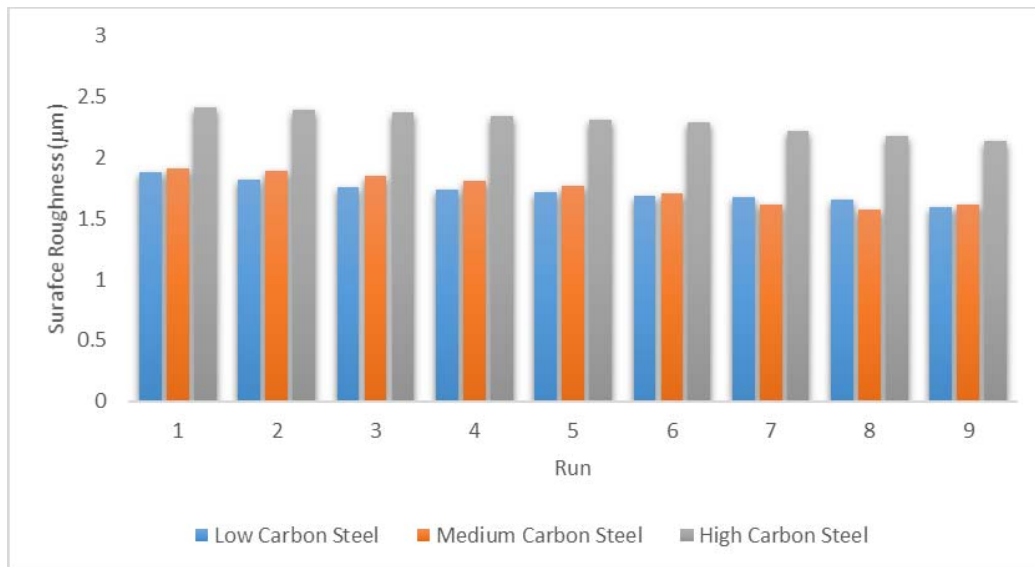


Figure 7: Surface Roughness during machining with Soluble Oil

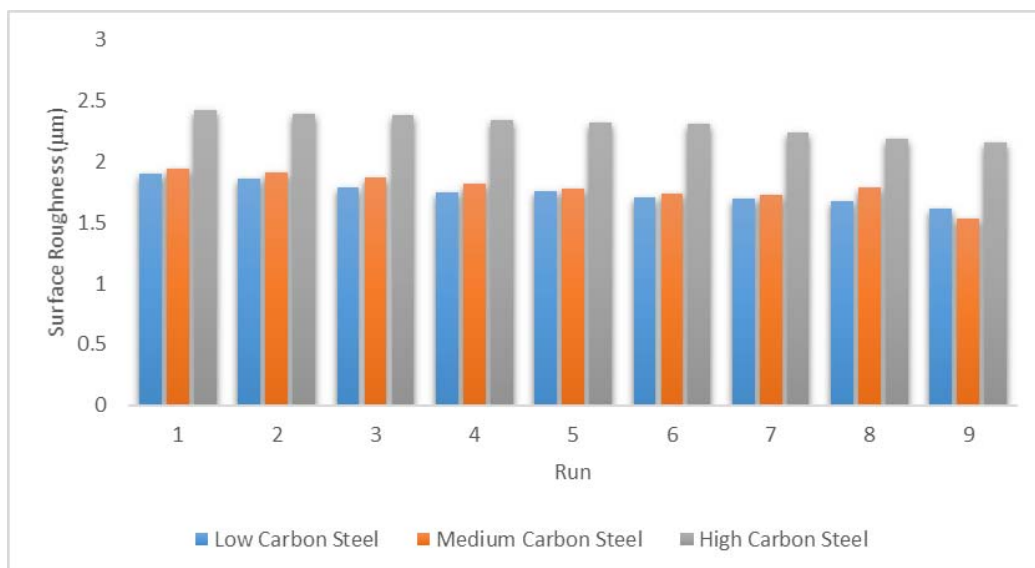


Figure 8: Surface Roughness during machining with Spent Engine Oil

Figure 9 shows a plot of the Material Removal Rate (MRR) as cutting speed increases while machining the three carbon steel types using soluble oil as cutting fluid. From the figure, MRR was larger for low carbon steel signifying a better machinability index for low carbon steel when compared with medium and high carbon steels that both had lower MRR value. The similar

MRR values for low carbon steel and high carbon steel resulted from the close percentage carbon values for both steel types. A similar trend was observed in MRR while machining with spent engine oil.

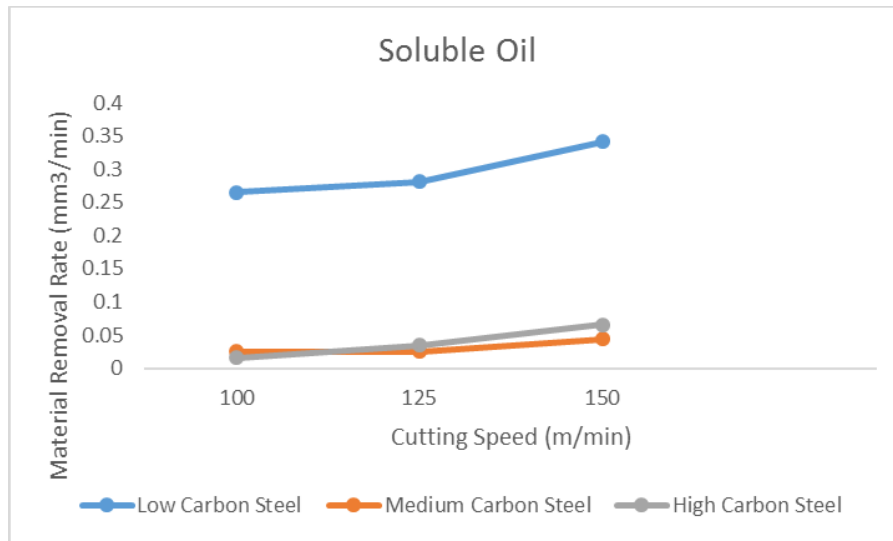


Figure 9: Material Removal Rate at various Cutting Speeds

Conclusion

In this study, an attempt was made to investigate the effect of material composition especially carbon content on machinability of steels. The effect of various machining parameters on surface roughness and material removal rate has been established with the following conclusions drawn at the end of the experiment.

1. Feed rate had the most significant effect on Surface roughness and MRR during machining of carbon steels using soluble oil and spent engine oil as cutting fluid.
2. Machinability increased with a reduction in carbon content of steels.
3. Spent engine oil was a better lubricant compared with soluble oil during machining of carbon steels.

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