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Effects of Cutter Geometry and Cutting Parameters on Machining Al/SiC Metal Matrix Composites (MMC)

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ABSTRACT

Al/SiC Metal Matrix Composite (MMC) have now become one of the prominent materials in composite materials especially in automotive industry. It has gained tremendous demand due to their tailored properties such as lightweight, high strength and wear resistant. However, these materials are classified as poor machinability material due to the presence of the hard-abrasive reinforcement particles within the matrix. Moreover, the lack of commercialization of a specific cutting tool for machining MMC materials is the source of several inherent problems such as rough machined surface and high cutting temperature. Furthermore, most of the researches on machining MMC are merely focus only on the effect of cutting parameters. Addressing to this matter, the development of new cutter design specifically for machining MMC are necessitate. Therefore, the aim of this paper is to study the combined effect between cutter geometrical features (helix angles, rake angles, clearance angles, number of flutes) and cutting parameter (cutting speed, feed rate and depth of cut) towards the machining performances namely surface roughness, cutting force and material removal rate. From the conducted experimental work, it was found that all of the considered factors has significant effect on the machining performances. As a conclusion, the obtained relationship between the responses with the cutter geometrical features and machining parameters can be used for the development of new cutter design specifically for machining Al/SiC MMC material.

Keywords: Al/SiC, Metal matrix composite, Cutter geometry, Machining performances

1. INTRODUCTION

The development of such sophisticated and modern technologies has led to the development of new material namely metal matrix composites (MMC) or particularly Al/SiC. Its unique mechanical properties such as low density, high strength, heat-resistant, wear-resistant and light weight has made it as a favorable material especially in automotive industry [1-2]. In general, Al/SiC consist of mixture between aluminum matrix and SiC particles reinforcement. The properties of the Al/SiC can be alter by the mixture composition between those two materials [3]. Mostly, MMC are manufacture through either by casting or infiltration process. For this reason, secondary process such as deburring and machining are requiring for achieving the final part dimension.

However, there are few issues faced by the manufacturer when it comes to machining MMC material. The main problems with this material are due to the non-homogeneous and anisotropic of the material. In addition, the presence of the abrasive nature of the

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reinforcement combined with the metal matrix has resulted in complexity during the machining process [4].

Few reported works on machining MMC shows that some common problems faced were rapid tool wear, rough machined surface, excessive cutting temperature and high cutting force [5-6]. The literature also revealed that the mechanic of shearing process for MMC material are differ from metal in which can lead to significant deterioration in the properties especially at the sub-surfaced level. It is therefore, the need to further improve on the mechanic of shearing process for MMC material are necessitate for the success of machining. It is well known that the mechanic of shearing process is closely related with the cutting parameters and cutter angles i.e. rake angle, helix angles, clearance angles and number of flutes as depicted in Figure 1. Therefore, thorough investigation to study the behaviour of the particle in the matrix when it contacts with the cutting tool can help to improve the machining performances.

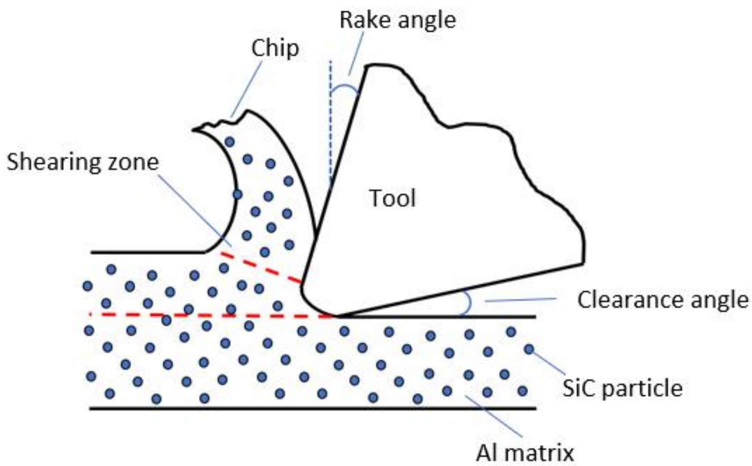

Figure 1. Mechanic of cutting for Al/SiC material.

1.1 Cutter Geometrical Features

The geometrical features of end mill consist of a core diameter, inscribed circle diameter, rake angle, clearance angle and helix angle. Each of the geometric features has their specific function and will significantly affect the machining performance. Figures 2 and 3 show the end mill geometrical terminology and the cutting angles respectively. Rake angle can have a significant effect on the cutting forces, stress distribution, chip deformation, cutting edge stiffness and rigidity of the tool. An end mill with a positive rake angle will improve machinability, thereby producing a lesser cutting force and cutting temperature. In addition, cutting forces and power were minimized when using a tool with high rake angle, and produced a good surface finish. However, too large a rake angle reduces the edge strength of the tool due to friction and stress distribution. Thus, a proper selection of rake angle value is vital and needs to be considered especially for the case of Al/SiC material which are non-homogeneous.

Clearance angle can also affect the performance of a cutting tool. Clearance angle is the angle between the cut surface and the clearance flank on the cutter. To obtain a good tool life a high value of clearance angle is preferred. However higher values of clearance angle tend to weaken the cutting edge, which becomes overheated because of poor heat transfer from the cutting edge. In the case of end mills, smaller clearance angles reduce the chip space for the same number of teeth. In such cases, primary and secondary clearances are provided. The value of clearance angles also depends on the diameter of the end mill. Smaller end mills have larger relief angles. For the case of Al/SiC material, moderate relief angle value is require in order to control and prevent the tool from rubbing with the workpieces. A high relief angle can also enhance the process damping and stability.

Helix angle is the angle formed by a line tangent to the helix and a plane through the axis of the cutter or the cutting edge angle, which a helical cutting edge makes with a plane containing the axis of a cylindrical cutter. A large helix angle can reduce tool deflection by transferring stress vertically which allows the end mill to produce vertical chip ejection. The shear stress and friction energy increased as the helix angle increased. In addition, greater shearing action results in increased speeds and feeds and faster stock removal. Helix angle permits several teeth to cut simultaneously which result in smoother cutting action. Figure 2 shows the details of end mill cutting angles.

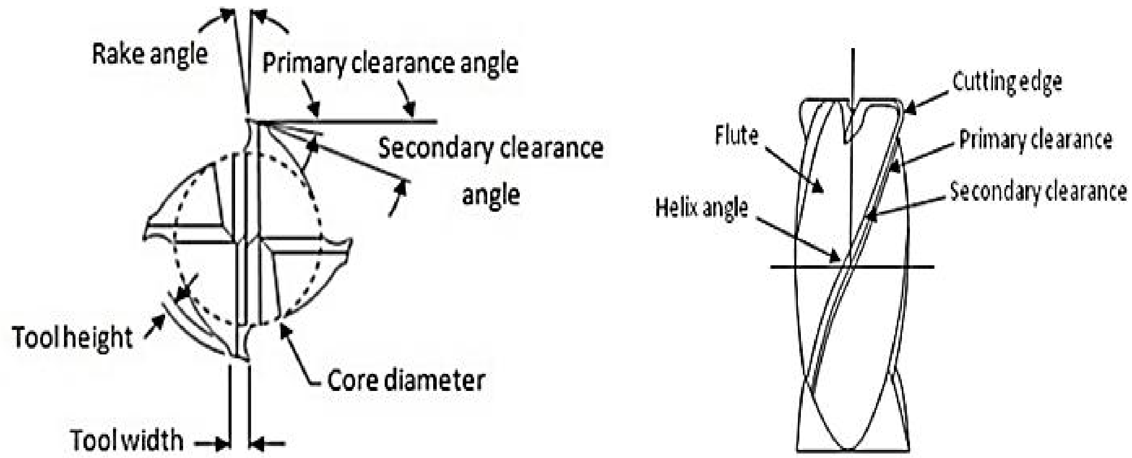

Figure 2. End mill cutting angles.

1.2 Cutting Parameters

Cutting parameters are one of the factors that play a huge role in machining operations. Generally, cutting speed, feed rate and depth of cut are three factors that are often regulated by a machinist. Cutting speed or spindle speed refers to the relative velocity difference between the surface of a workpiece and the cutting tool. It is measured in revolution per minute (RPM) and controlled the rotation of the spindle where the tool is held. the cutting energy, shear stress and surface finish for machined material are always influenced by cutting speed. Therefore, cutting speed should be well controlled during machining operation.

Furthermore, feed rate is the relative velocity at which the cutter is advanced along the workpiece; its vector is perpendicular to the vector of cutting speed. It is measured in units of millimetre per revolution (mm/rev) or millimetre per minute (mm/min). Feed rate is required to drive the tool into machined part or drive machined part to tool. The cutting speed and feed rate values are determined based on the required surface finish, machine capability, the maximum cutting force permitted by rigidity of tools and the workpiece hardness level. Along with cutting speed and feed rate is the depth of cut. Depth of cut is the distance of the tool advancing into the material which will determine the amount of material been remove.

2. EXPERIMENTAL SETUP

CNC Tool cutter grinder Michael Deckel S20 Turbo was used to fabricate the cutter made from tungsten carbide rod according to the determine design parameters. The selection of the cutter material type is based on material reliability and cost. Table 1 shows information on the type of end mill used along with its measurements. A total of eight different end mill design are produced with various helix angles, rake angles, clearance angles and number of flutes as shown in Figure 3. Machining parameters such as cutting speed, feed rate and depth of cut are also varied in order to investigate the effects towards the machining performances as shown in Table 2. While Table 3 shows the information of Al/SiC metal matrix composite (MMC) material used in the experiment.

Table 1 End mill specification

Material	Diameter	Overall Length	Bottom
WC – K2	8 mm	60 mm	Flat

Table 2 Design parameter for end mill

Tool Design	Helix angle (°)	Rake angle (°)	Clearance angle (°)	Number of flutes	Spindle speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)
1	30	5	6	2	1000	100	0.5
2	30	5	6	4	4000	500	1.5
3	30	15	18	2	1000	500	1.5
4	30	15	18	4	4000	100	0.5
5	60	5	18	2	4000	100	1.5
6	60	5	18	4	1000	500	0.5
7	60	15	6	2	4000	500	0.5
8	60	15	6	4	1000	100	1.5

Table 3 Workpiece used in the experiment

Metal Matrix Composites (MMC)	Al/SiC
Process	Infiltration Method
Composition (vol%)	SiC-70%; Al-30%
Density (g/cm3)	3.0
Flexural strength (MPa)	340
Young's Modulus (GPa)	260
Poisson's Ratio	0.20
Fracture Toughness (MPa*m1/2)	8
Thermal Expansion (×10-6/K)	7
Thermal Conductivity (W/m*K)	160
Specific Heat (J/g*K)	0.6
Volume Resistivity (Ω*cm)	1×10-5
Hardness	HRB-110
	HRC-35
Dimension	10 cm×5 cm×2 cm

The 3-axis HAAS CNC milling machine was used to conduct slot milling cutting tests on workpiece to investigate the relationship between machining surface roughness, cutting force and material removal rate (MRR) with respect to the changes in tool geometrical features and machining parameters.

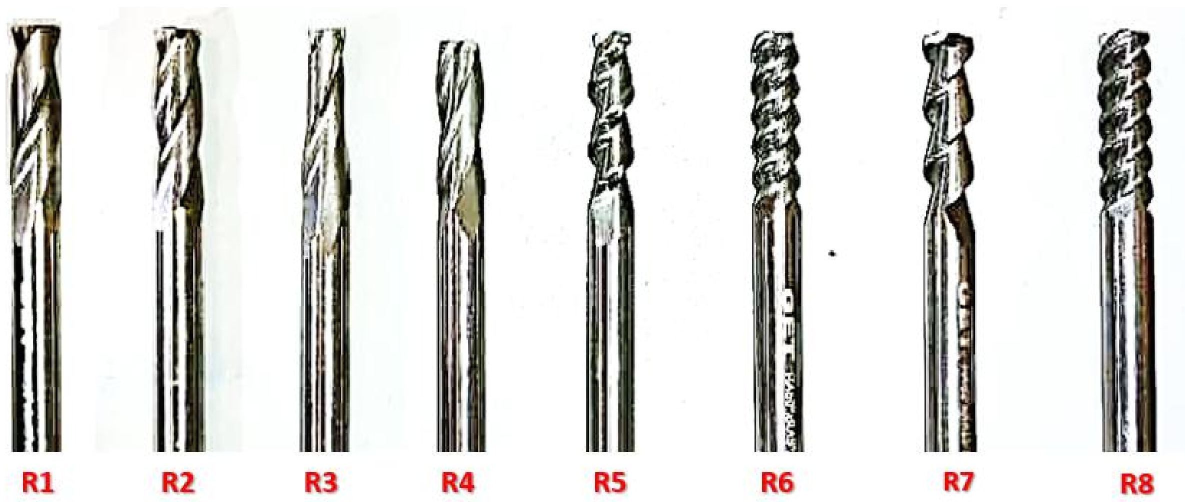

Figure 3. Fabricated end mill with different geometrical features.

3. RESULTS AND DISCUSSION

Table 4 and Figure 4 tabulated the results obtained from the machining test. From the results, it shows the variation on each of the responses value which indicate that both factors i.e. cutter geometry and cutting parameter has significant effects.

Table 4 Results of the surface roughness and removal rate.

	Surface roughness (µm)				Cutting force (N)				Material removal rate (g)			
	1	2	3	**Average**	1	2	3	**Average**	1	2	3	**Average**
1	1.78	1.82	1.84	**1.83**	702.45	714.20	709.00	**708.55**	0.54	0.55	0.54	**0.54**
2	4.11	4.05	3.98	**4.07**	433.20	425.84	427.25	**428.76**	1.46	1.51	1.48	**1.47**
3	1.98	2.05	2.11	**2.05**	1896.72	1942.46	1929.63	**1922.94**	1.92	1.87	1.89	**1.88**
4	2.82	2.72	2.64	**2.70**	192.68	166.34	184.18	**181.07**	0.31	0.38	0.36	**0.40**
5	2.12	2.11	2.08	**2.12**	1674.86	1448.83	1672.31	**1598.67**	1.53	1.48	1.50	**1.48**
6	1.21	1.28	1.34	**1.29**	810.64	890.47	883.65	**861.59**	0.40	0.48	0.43	**0.42**
7	2.12	1.98	1.85	**1.97**	872.37	863.28	850.03	**861.89**	0.35	0.36	0.34	**0.31**
8	1.92	1.89	1.84	**1.91**	542.96	588.32	562.40	**564.56**	1.50	1.66	1.57	**1.56**

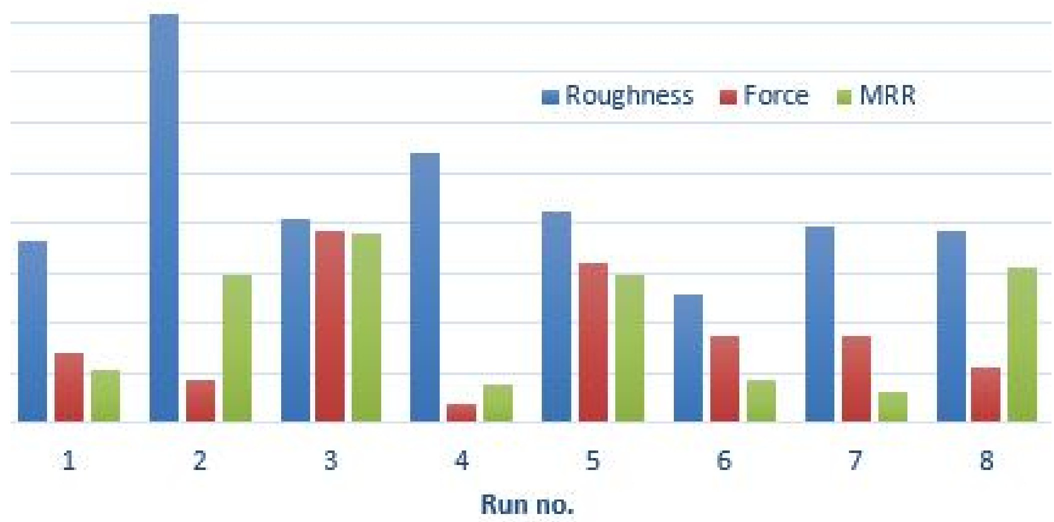

Figure 4. Graph of each machining performances between runs.

Figure 5 shows the machining slot produced for all the runs. From the observed machining surface condition, run no. 2 (with 30° helix, 5° rake, 6° clearance and 4 flutes) produced the highest Ra value with an average of 4.07 μm. The slot surface for run no. 2 clearly shows the cutter marks formation and black spot which represent the SiC particles.

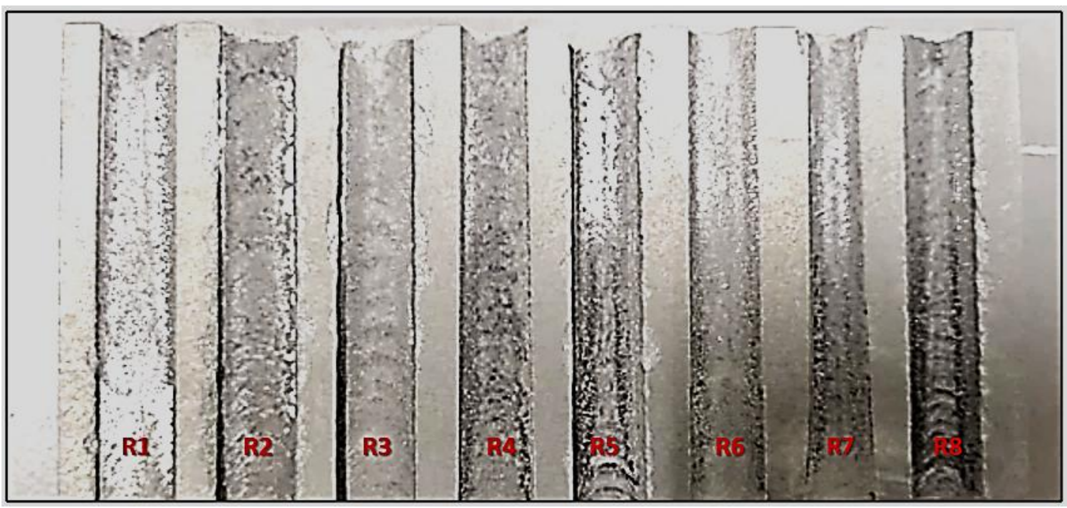

Figure 5. Machining slot.

Further analysis using the Signal to Noise (SN) ratio graph was used to investigate the effects on each factor. Figure 6 shows the SN ratios graph of surface roughness. The graph shows that the surface roughness produced are significantly influence by helix angle and spindle speed followed by clearance angle, number of flutes and depth of cut. A low surface roughness value indicates a better surface profile. Therefore, 'smaller is better' is chosen for the target condition. Based on the result, a lower helix angle value (30°) is required to produce a smooth surface roughness while a higher spindle speed value (4000 rpm) is required to obtain the same surface roughness. This is also accompanied by clearance angle (6°), number of flutes (4) and depth of cut (1.5 mm) which has the same condition with helix angle and spindle speed. Rake angle (15°) and feed rate (500 mm/min) have the same graph pattern that is to choose a large value.

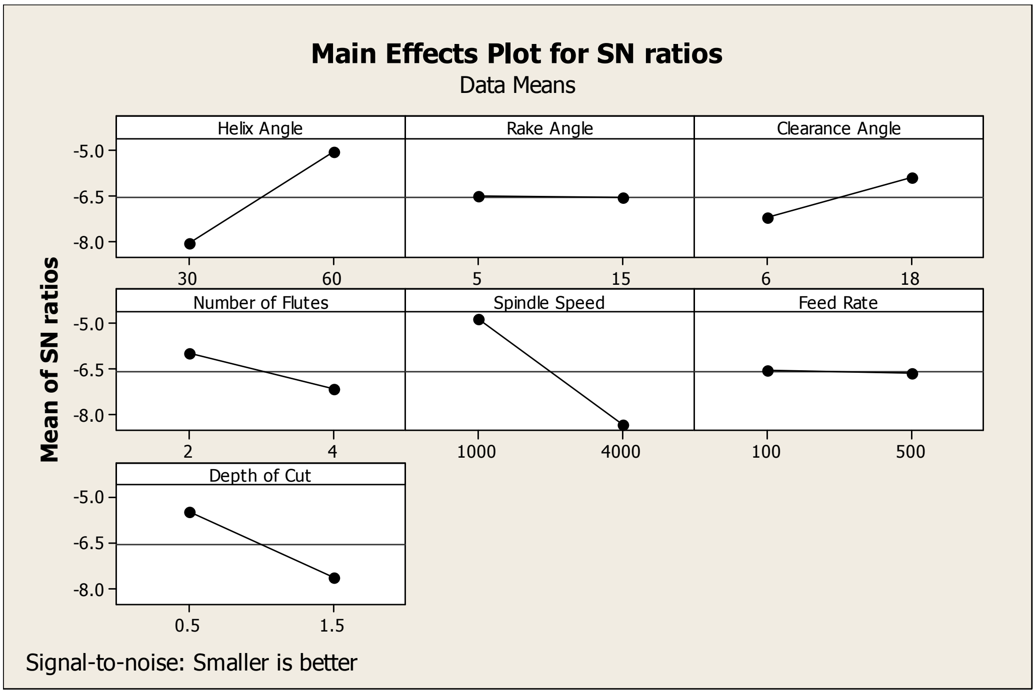

Figure 6. SN ratios graph of surface roughness.

Figure 7 shows the SN ratios graph for cutting force. Lower cutting force values are required to produce good machining quality. This is because the cutting force is often closely related to the friction that leads to the cutting temperature. Therefore, 'smaller is better' is chosen to obtain good machining quality. This graph shows that the cutting force is influenced by helix angle and spindle speed followed by rake angle and number of flutes. Based on this graph, the low cutting force value can be obtained if the helix angle value (60°) clearance angle value (18°), feed rate value (500 mm/min) and depth of cut value (1.5 mm) is high and the spindle speed value (1000 rpm), rake angle value (5°) and number of flutes value (2) is low.

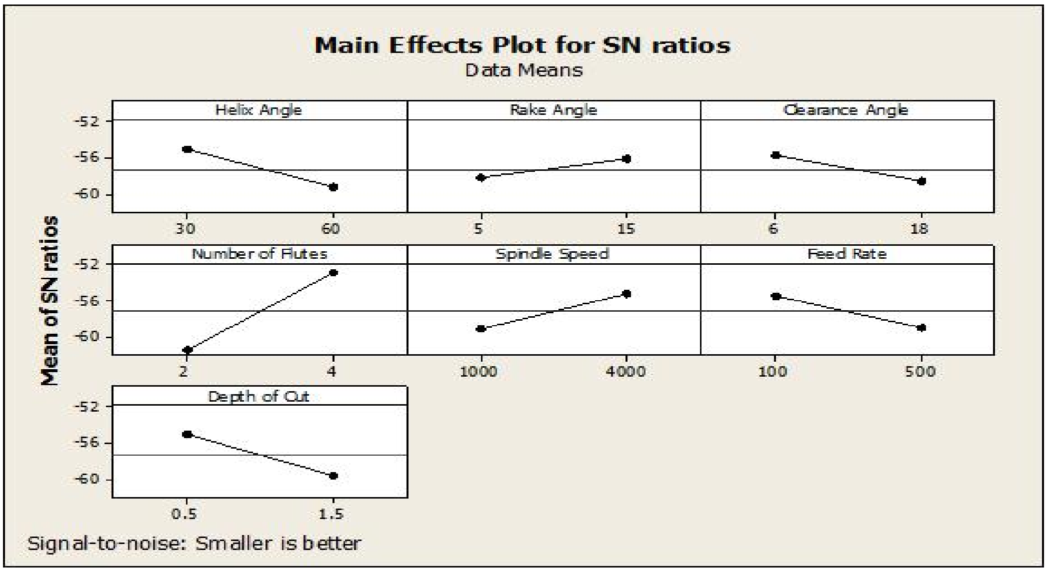

Figure 7. SN ratios graph of cutting force.

Figure 8 shows the SN ratios graph for MRR. The situation is different for MRR where 'larger is better' is selected to obtain high quality machining performances. Most of the graph forms for each factor influencing the MRR are balanced except for the depth of cut. A higher depth of cut value (1.5 mm) will produce the highest MRR. As explained in Section 1.2, depth of cut is the distance of the tool advancing into the work material that reflect on the amount of material been remove.

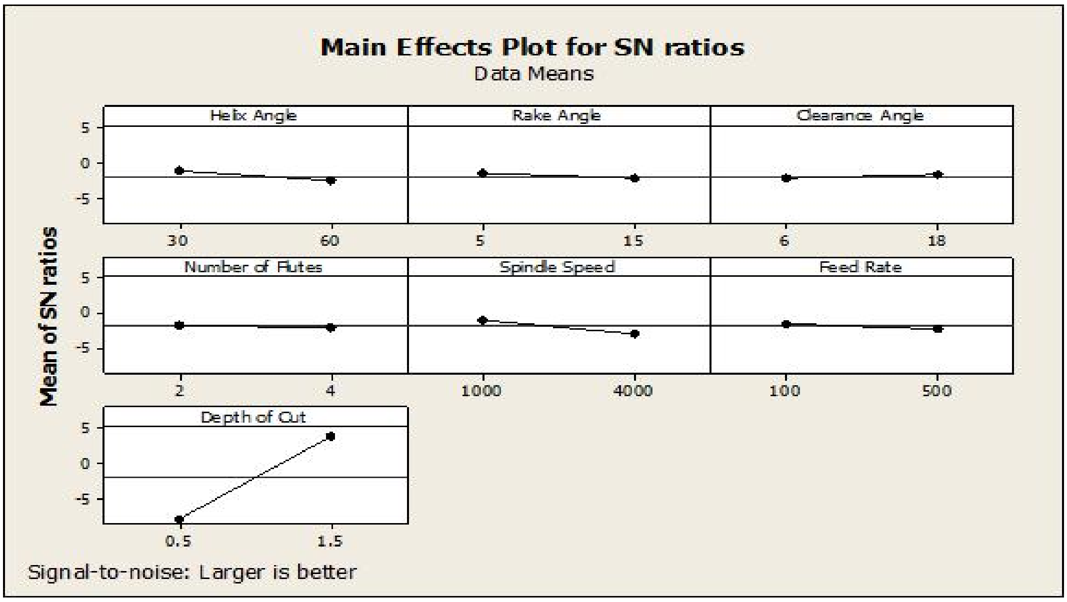

Figure 8. SN ratios graph of MRR.

4. CONCLUSION

From the conducted experiment, it shows that the both factors which are cutter geometrical features of end mill (helix angle, rake angle, clearance angle and number of flutes) and machining parameters (spindle speed, feed rate and depth of cut) have significant effects on machining performances (surface roughness, cutting force and MRR). Decreasing the helix angle and increasing spindle speed value will improve the machining surface roughness. However, increasing helix angle and decreasing spindle speed will improve cutting force. In conclusion, this work serve as a basic investigation on the effects of cutter geometrical features and machining parameters, further works are require especially on the mechanic of shearing and behavior of the particle in the matrix when it contacts with the cutting tool and its relation to the machining performances.

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