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# Effect of Addition of Nanoclay on Machinability of Al/Nanoclay Metal Matrix Composites

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## ABSTRACT

**In this study, machinability test was conducted on Al-Nanoclay metal matrix composites using lathe tool dynamometer. Composites were prepared with aluminium as the matrix and nanoclay particles with 2, 4, 6 percentage by weight as reinforcement. The effect of clay particles and machining parameters such as cutting speed, feed rate and depth of cut on tangential force and chip formation was studied. From the results it is observed that the tangential force applied by the tool on MMC, facilitate chip breaking and the generation of chips significantly depends on feed but almost independent of speed. These results reveal the roles of the nanoclay reinforcement particles on the machinability of MMCs and provide a useful guide for a better control of their machining processes**.

**Keywords –Cutting Speed, Chip breaking, Depth of Cut, Feed rate, Machinability**

## I. INTRODUCTION

Amongst the material variables, the mechanical properties of fiber and matrix, particularly the failure strains, interface properties and fiber configuration play important role in determining fracture resistance and damage tolerance of the composites[1-2]. Nanostructure materials such as nanocomposites provide opportunities to explore new fracture behavior and functionality beyond those found in conventional materials. The presence of small amounts of nanoparticles in metal matrix can improve the wear resistance and hardness of composites. Obviously, the higher the hardness of the material, the more the abrasive wear experienced by the cutting tool in addition. Nevertheless the incorporation of the microsize hard particles makes the machining of MMCs difficult [3], and diamond tools are often necessary [4]. There have been some investigations on the machining of MMCs, dealing with tool wear [5], surface / subsurface quality [6] and chip formation [7]. However until now, no particular work is done exclusively to assess the importance of nanoclay content on the machinability parameters. The objective of the present research is to gain a deeper understanding of the effects of nanoclay particles on machinability forces and Chip formation with varied machining parameters when cutting nanoclay / Al MMC specimens.

## II. EXPERIMENTAL DETAILS

The matrix material used for the MMCs in this study, Al, has excellent casting properties and reasonable strength. This alloy is best suited for mass production of lightweight metal castings. chemical composition of Al6061 shown below

- Silicon minimum 0.4%, maximum 0.8% by weight
- Iron no minimum, maximum 0.7%
- Copper minimum 0.15%, maximum 0.40%
- Manganese no minimum, maximum 0.15%
- Magnesium minimum 0.8%, maximum 1.2%
- Chromium minimum 0.04%, maximum 0.35%
- Zinc no minimum, maximum 0.25%
- Titanium no minimum, maximum 0.15%
- Other elements no more than 0.05% each, 0.15% total
- Remainder Aluminum

The nanoclay of 10-60 nm size were used as the reinforcement and the nanoclay content in the composites was varied from 2 to 6% in steps of 2% by weight. Liquid metallurgy technique was used to fabricate the composite materials in which the clay particles were introduced into the molten metal pool through a vortex created in the melt by the use of an alumina-coated stainless steel stirrer. The coating of alumina on the stirrer is essential to prevent the migration of ferrous ions from the stirrer material into the molten metal. The depth of immersion of the stirrer was about two-thirds the depth of the molten metal. The stirrer was rotated at 550 rpm. The pre-heated (500 °C) nanoclay particles were added into the vortex of the liquid melt which was degassed using pure nitrogen for about 3 to 4 min. The resulting mixture was tilt poured into preheated permanent moulds.

## III. MACHINABILITY TEST

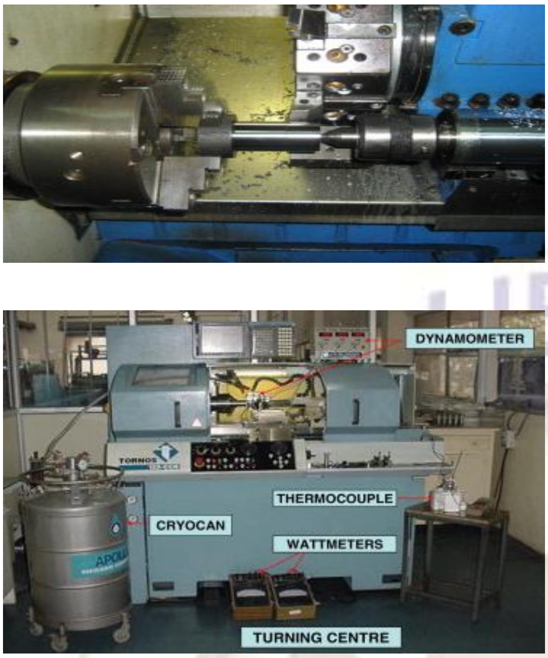

**Fig. 1. Experimental set up**

Machinability test was carried out by turning the specimens in a CNC lathe. The cutting speeds selected were 200, 315, 400 and 500 rpm. The depth of cut was 0.2, 0.5, 0.8 and 1 mm and the feed-rates were 0.1, 0.2, 0.32 and 0.4 mm/rev. The cutting forces (namely, the tangential, axial and radial forces) in three perpendicular directions were measured by means of a computer interfaced dynamometer on which cutting tool was mounted. The cutting tool material was high-speed carbide tool. The tool signature is follows

| | |
|---|---|
| Brake rake angle | 8°, |
| Side rake angle | 20.5° |
| End clearance angle | 12° |
| Side cutting angle | 10° |
| Slide cutting angle | 75° |
| End cutting angle | 80° |
| Nose radius | 1 mm |

The number of chips produced per gram of the material removed was counted.

## IV. RESULTS

Because of the large volume of results obtained, only the values of the tangential cutting force for various cutting speeds, federates and depth of cut are presented. The axial and radial cutting forces were consistently more or less proportional to the tangential cutting force and are therefore not reported.

Fig.2. shows the results for the machining of plain aluminium at depths of cut of 0.2, 0.5, 0.8 and 1 mm respectively. It can be seen that there is a general trend of increase in tangential cutting force with increase in cutting Speed. The cutting force also tends to increase as federate or depth of cut is increased.

The few anomalous cases can be attributed to experimental error. The same trend can be seen in Figs.3, 4,and 5 for composites with 2, 4 and 6% nanoclay reinforcement. i.e tangential cutting force increases with increase in cutting speed, federate and depth of cut.

The number of chips produced per gram when machining the composites under specified conditions, increases with the increase of amount of nanoclay in the composites as shown in the Fig. 6

The nanoclay particulate apparently introduces discontinuities in the material and act as stress raisers, There by resulting in the frequent fracture of chips during machining.

The production of small chips is one of the criteria of good machinability since very long chips have a tendency to wrap around the tool at high machining speeds limiting the rate of machining; the aluminum industry is constantly in need of fast machining alloys.

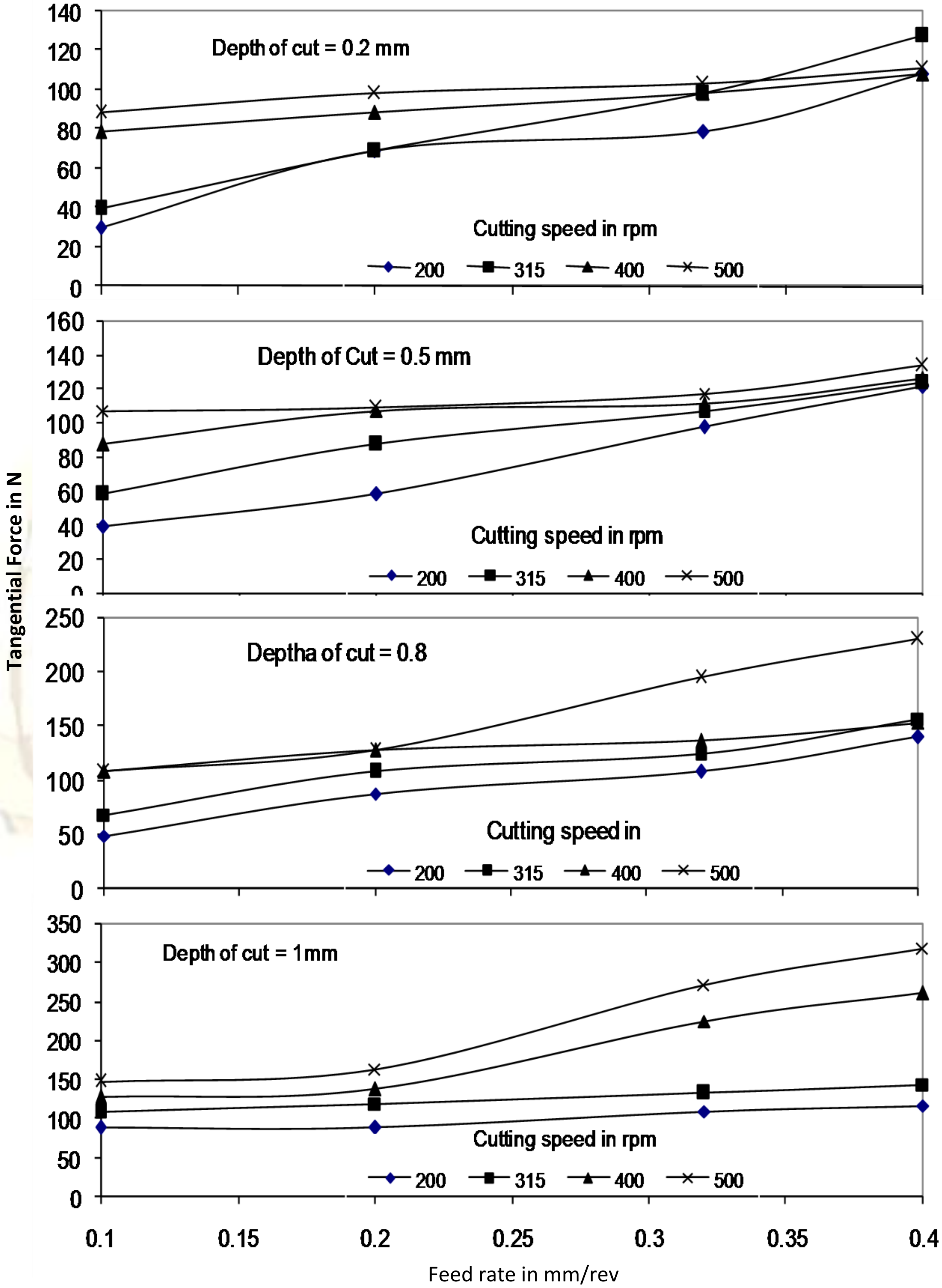

Fig. 2. Typical plot of tangential force vs. feed rate for Al matrix alloy.

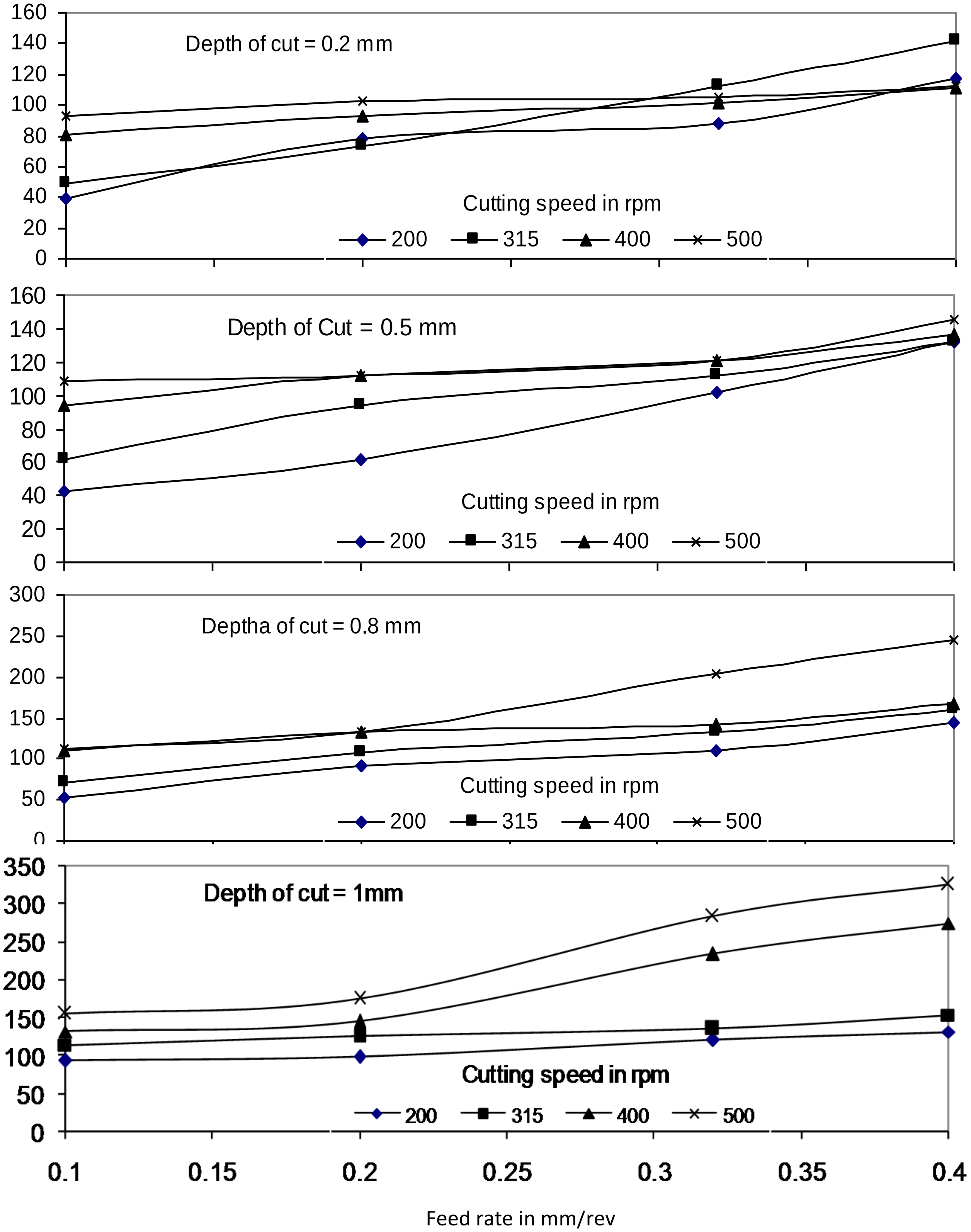

**Fig. 3. Typical plot of tangential force vs. feed rate for Al/2% nanoclay Composites.**

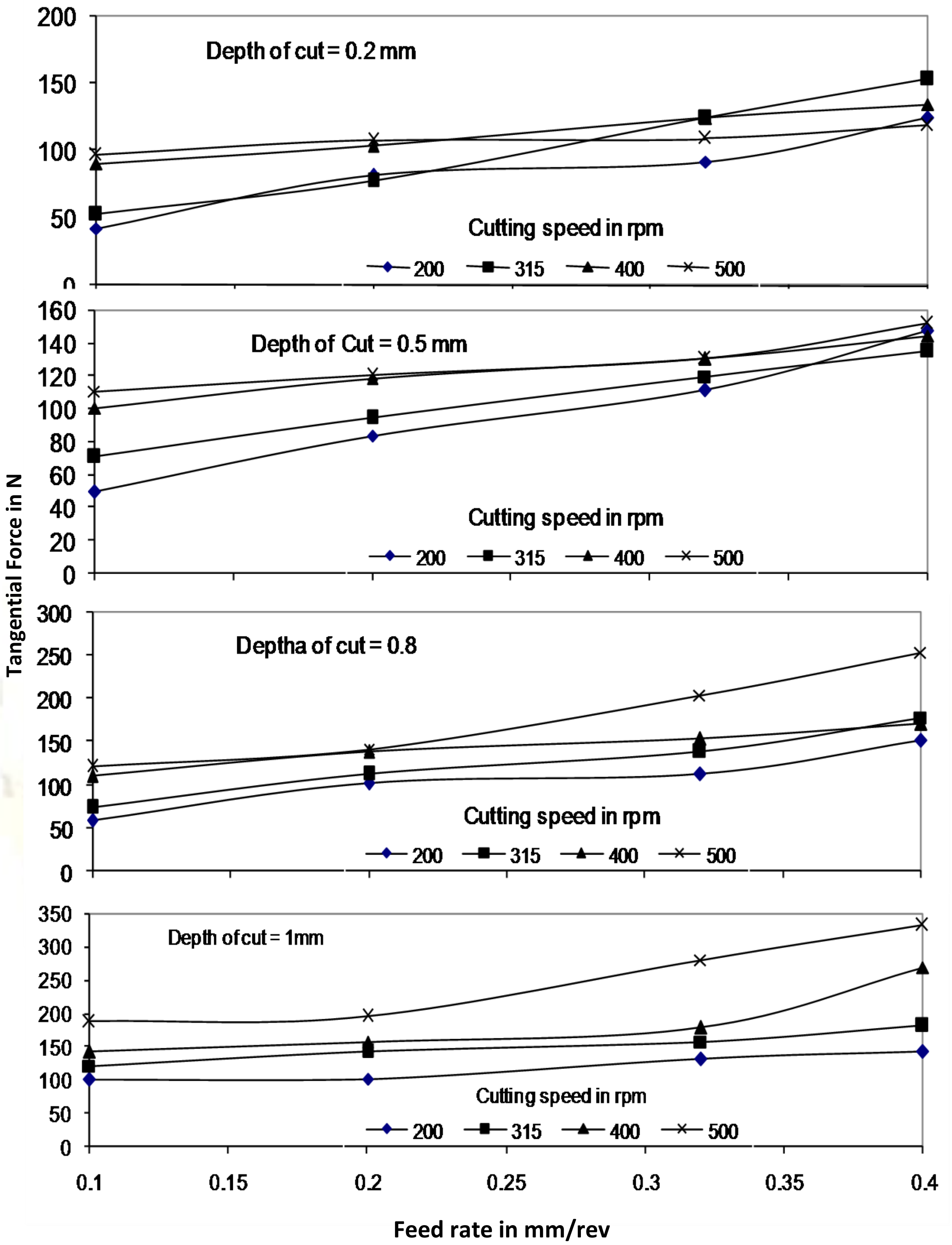

Fig. 4. Typical plot of tangential force vs. feed rate for Al/4% nanoclay Composites.

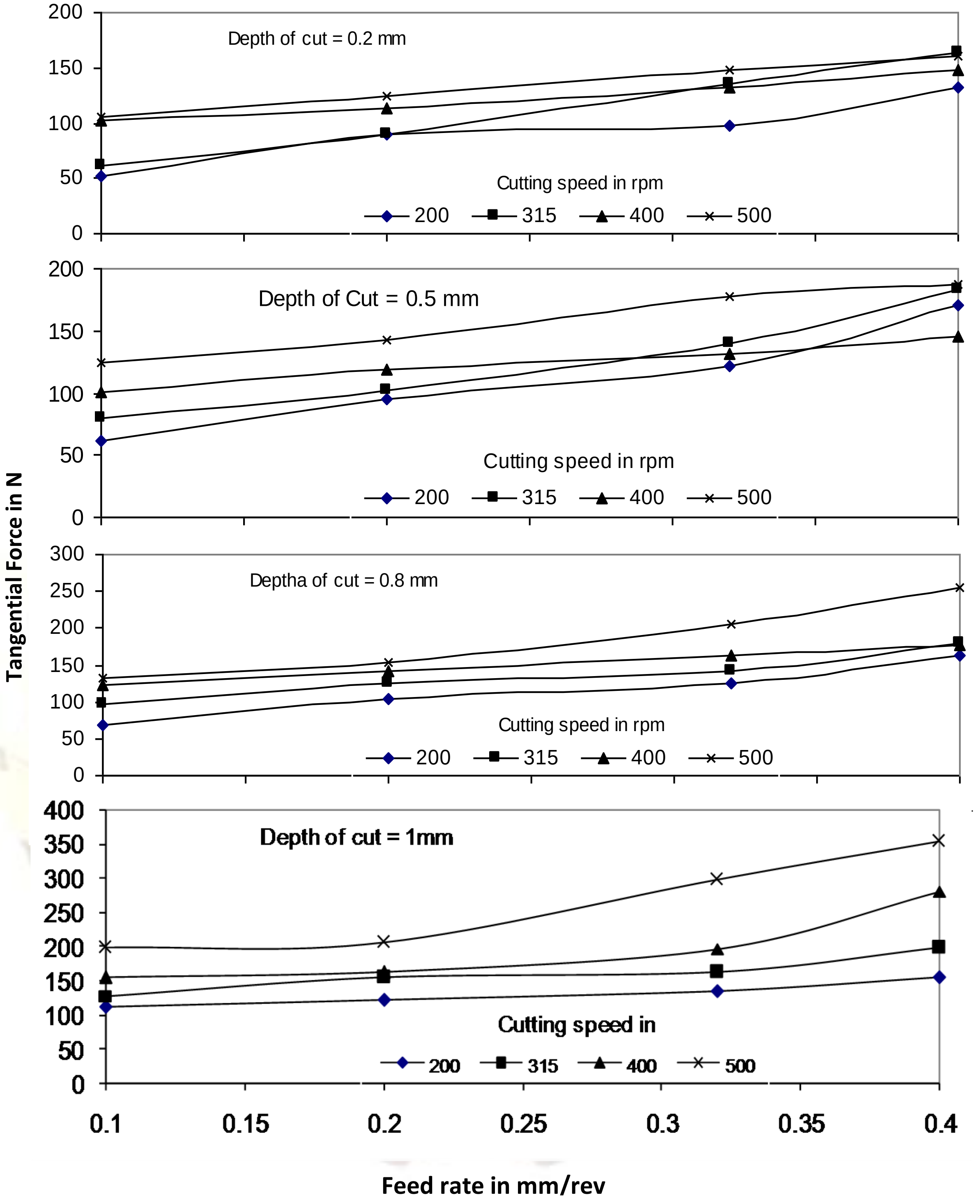

Fig. 5. Typical plot of tangential force vs. feed rate for Al/6% nanoclay composites.

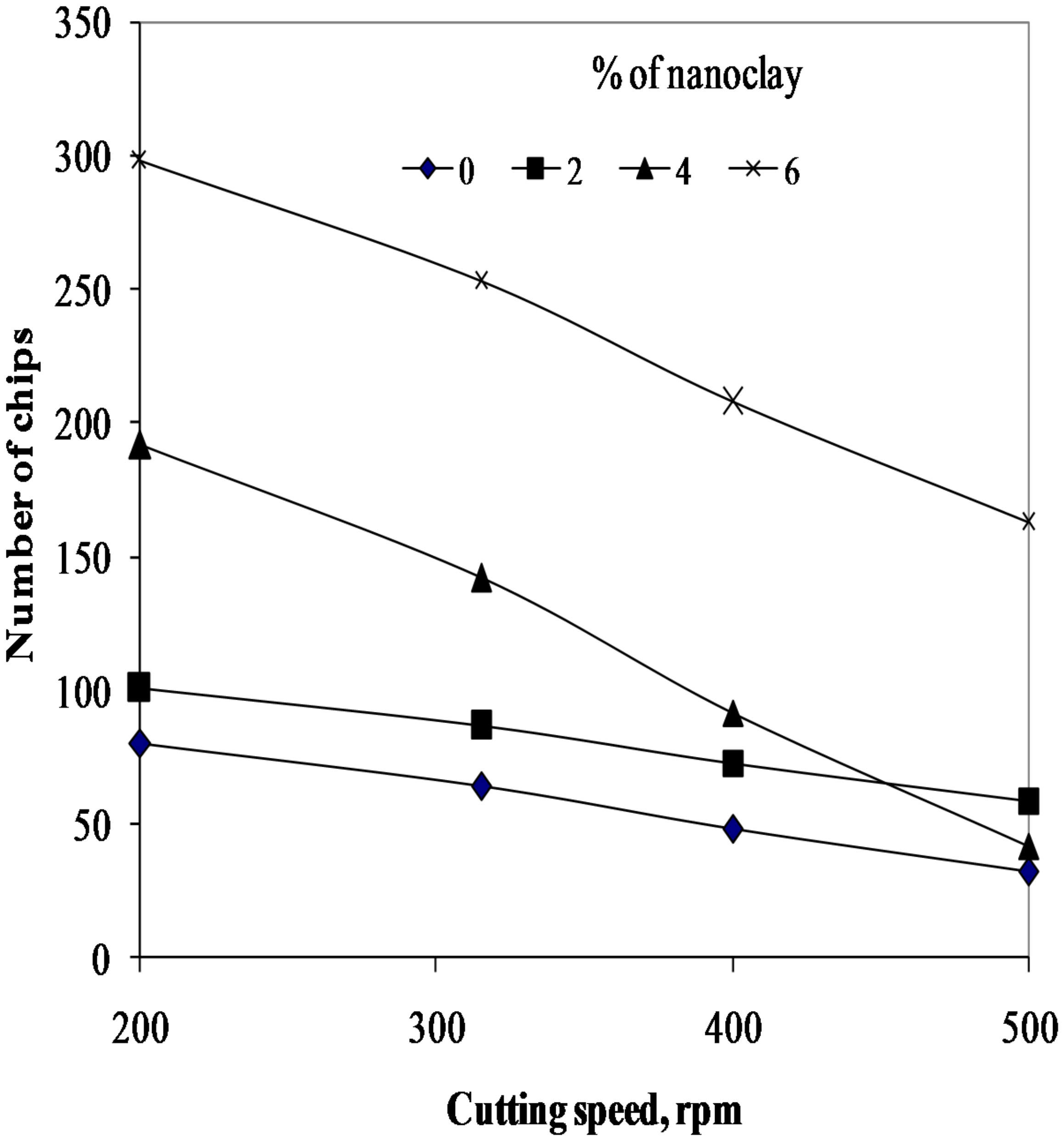

Fig. 6 Number of chips per gram of nanoclay dispersed in Al MMCs as a function of speed.

**Table 1. Experimentally obtained machining force (Tangential force) for Al matrix and Al/nanoclay MMCs**

| Specimen | Al matrix alloy | | | | Al/2% nanoclay | | | | Al/4% nanoclay | | | | Al/6% nanoclay | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feed rate mm/sec | 0.1 | 0.2 | 0.32 | 0.4 | 0.1 | 0.2 | 0.32 | 0.4 | 0.1 | 0.2 | 0.32 | 0.4 | 0.1 | 0.2 | 0.32 | 0.4 |
| Speed, rpm | Dept of cut = 0.2 mm | | | | | | | | | | | | | | | |
| 200 | 29 | 69 | 78 | 108 | 39 | 78 | 88 | 117 | 42 | 82 | 92 | 125 | 52 | 89 | 98 | 132 |
| 315 | 39 | 69 | 98 | 128 | 49 | 73 | 113 | 142 | 53 | 78 | 125 | 154 | 62 | 90 | 135 | 164 |
| 400 | 79 | 88 | 98 | 108 | 81 | 93 | 101 | 112 | 91 | 104 | 125 | 135 | 102 | 113 | 132 | 148 |
| 500 | 88 | 98 | 103 | 111 | 93 | 103 | 105 | 113 | 97 | 108 | 109 | 119 | 105 | 125 | 148 | 160 |
| Dept of cut = 0.5 mm | | | | | | | | | | | | | | | | |
| 200 | 39 | 59 | 98 | 122 | 42 | 62 | 102 | 132 | 50 | 84 | 112 | 148 | 62 | 95 | 121 | 170 |
| 315 | 59 | 88 | 108 | 124 | 62 | 94 | 112 | 132 | 71 | 95 | 120 | 135 | 80 | 102 | 140 | 183 |
| 400 | 88 | 108 | 112 | 126 | 94 | 112 | 121 | 136 | 101 | 119 | 131 | 145 | 101 | 119 | 131 | 145 |
| 500 | 108 | 110 | 118 | 134 | 109 | 112 | 121 | 145 | 111 | 121 | 131 | 152 | 125 | 142 | 178 | 188 |
| Dept of cut = 0.8 mm | | | | | | | | | | | | | | | | |
| 200 | 49 | 88 | 108 | 141 | 52 | 92 | 109 | 145 | 59 | 102 | 112 | 152 | 68 | 103 | 125 | 163 |
| 315 | 69 | 108 | 125 | 157 | 72 | 108 | 132 | 161 | 74 | 112 | 138 | 178 | 98 | 125 | 141 | 179 |
| 400 | 108 | 128 | 137 | 154 | 109 | 132 | 143 | 167 | 111 | 138 | 154 | 171 | 123 | 141 | 163 | 178 |
| 500 | 108 | 128 | 195 | 231 | 112 | 132 | 203 | 245 | 121 | 142 | 204 | 254 | 132 | 154 | 205 | 255 |
| Dept of cut = 1 mm | | | | | | | | | | | | | | | | |
| 200 | 88 | 89 | 110 | 117 | 93 | 98 | 121 | 132 | 101 | 102 | 132 | 142 | 111 | 121 | 135 | 154 |
| 315 | 108 | 119 | 132 | 144 | 115 | 125 | 136 | 154 | 121 | 142 | 158 | 181 | 128 | 154 | 162 | 198 |
| 400 | 128 | 137 | 225 | 261 | 132 | 145 | 234 | 275 | 142 | 158 | 178 | 270 | 154 | 163 | 197 | 281 |
| 500 | 147 | 164 | 271 | 318 | 156 | 175 | 284 | 325 | 188 | 195 | 281 | 332 | 198 | 205 | 298 | 354 |

**Table 2. Number of chips/gram formation during machining of Al matrix and Al/nanoclay MMCs**

| Specimen | Al matrix alloy | | | | Al/2% nanoclay | | | | Al/4% nanoclay | | | | Al/6% nanoclay | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feed rate mm/sec | 0.1 | 0.2 | 0.32 | 0.4 | 0.1 | 0.2 | 0.32 | 0.4 | 0.1 | 0.2 | 0.32 | 0.4 | 0.1 | 0.2 | 0.32 | 0.4 |
| Speed, rpm | Dept of cut = 0.2 mm | | | | | | | | | | | | | | | |
| 200 | 222 | 160 | 142 | 59 | 303 | 228 | 202 | 101 | 571 | 421 | 375 | 192 | 756 | 562 | 510 | 298 |
| 315 | 139 | 106 | 75 | 42 | 252 | 201 | 130 | 87 | 413 | 335 | 209 | 142 | 669 | 551 | 367 | 253 |
| 400 | 59 | 53 | 48 | 43 | 101 | 91 | 84 | 73 | 136 | 126 | 105 | 92 | 302 | 269 | 230 | 208 |
| 500 | 33 | 31 | 29 | 26 | 72 | 67 | 65 | 59 | 52 | 47 | 47 | 42 | 248 | 230 | 194 | 163 |
| Dept of cut = 0.5 mm | | | | | | | | | | | | | | | | |
| 200 | 250 | 201 | 121 | 80 | 342 | 264 | 161 | 109 | 677 | 512 | 384 | 229 | 974 | 693 | 544 | 355 |
| 315 | 135 | 117 | 95 | 64 | 234 | 199 | 167 | 110 | 362 | 322 | 255 | 190 | 747 | 571 | 416 | 326 |
| 400 | 69 | 61 | 59 | 48 | 123 | 109 | 101 | 85 | 147 | 132 | 120 | 102 | 296 | 267 | 243 | 206 |
| 500 | 40 | 35 | 33 | 32 | 92 | 77 | 71 | 69 | 66 | 57 | 52 | 48 | 292 | 276 | 220 | 194 |
| Dept of cut = 0.8 mm | | | | | | | | | | | | | | | | |
| 200 | 289 | 222 | 181 | 101 | 376 | 282 | 238 | 135 | 695 | 512 | 466 | 270 | 934 | 716 | 590 | 390 |
| 315 | 170 | 136 | 117 | 75 | 286 | 234 | 192 | 128 | 477 | 370 | 300 | 198 | 730 | 575 | 510 | 400 |
| 400 | 84 | 75 | 70 | 59 | 151 | 129 | 119 | 98 | 173 | 156 | 140 | 112 | 363 | 332 | 288 | 251 |
| 500 | 68 | 58 | 38 | 32 | 155 | 129 | 84 | 71 | 110 | 88 | 61 | 52 | 396 | 318 | 239 | 205 |
| Dept of cut = 1 mm | | | | | | | | | | | | | | | | |
| 200 | 240 | 226 | 183 | 181 | 342 | 313 | 254 | 241 | 649 | 603 | 466 | 462 | 883 | 774 | 693 | 636 |
| 315 | 156 | 143 | 129 | 117 | 273 | 241 | 222 | 204 | 485 | 423 | 380 | 324 | 808 | 661 | 628 | 522 |
| 400 | 142 | 123 | 75 | 70 | 248 | 211 | 131 | 119 | 273 | 180 | 160 | 144 | 573 | 402 | 332 | 314 |
| 500 | 94 | 80 | 49 | 44 | 206 | 180 | 111 | 99 | 144 | 122 | 84 | 81 | 550 | 463 | 318 | 307 |

## V. DISCUSSION

It has been reported that no specific relationship exists between the cutting forces and cutting speed in the beginning of the machining process. It was found that the cutting forces increase with increasing cutting speed while machining the composites. This is due to increase in effective area of contact between the tool and the work piece which indirectly increases frictional forces at the tool-work piece interface [8]. The variation in the effective contact area at the tool-cutting surface explains the high force components involved in machining.

The test results show that the magnitude of forces measured during the machining of composite material is more when compared to the base alloy. However, the increase in the amount of force is not too high in the case of matrix alloy but in the case of particulates reinforced composites it is very high [9]. The tool life is limited by the amount of wear the tool experiences.

Examination of the wear land on the tool tip showed significantly scratched grooves parallel to the direction of chip flow and work piece movement. Such grooves are usually found in Metal Matrix Composites (MMCs) reinforced with hard dispersoids like nanoclay and are formed by the mixture of two-body and three-body abrasion between the work piece and the tool which is mainly due to the hard nature and irregular shape of the reinforcement and the loose reinforcement found during machining. Since glass short particulate reinforcement is also a hard reinforcement, obviously grooves were found parallel to the direction of chip flow [10].

The cutting speed has a more dominant influence on the volume of the material removal rate. If maximum cutting time between the tool changes is needed, a lower feed rate is preferable. A better surface finish can also be obtained, under these conditions. On the other hand, if greatest amount of material removed per tool is desired, then the largest possible feed rate should be chosen after giving proper consideration towards surface finish [11].

The cutting forces involved in machining the composites with reinforcement were found to be greater than that of all other composites including unreinforced alloy. Examination of the cutting tools revealed that the chip/tool contact lengths were shorter with the MMCs than the parent alloy. Hence it appears that the increase in cutting forces is explained by the presence of reinforcement, which reduces chip/tool adhesion and shear at the interface.

The most significant finding from the cutting force measurements was their sensitivity to tool wear [12].

The nature of the chip formed during machining of the composite as well as the matrix alloy changes with extent of the tool wear. When the tool is sharp, long washer type helical chips are formed, sometimes accompanied by small amount of washer type helical chip flow by the tool holder. Once the tool starts getting blunt, chip formed changes into short washer helical type. It is mainly due to that Al alloy is relatively softer and tends to adhere to the face of the cutting tool during machining. The material begins to pile-up on the tool resulting in a longer chip [13]. The nanoclay reinforcement content in the composite probably avoids the occurrence of shearing ahead of the cutting tool continuously without fracture and causes rapture intermittently producing segments of chips with smaller lengths. Hence the composite material which produces shorter chips without chip breakers is well suited for industrial applications.

## VI. CONCLUSIONS

- The power consumed for machining the composite is higher than that of the unreinforced alloy.
- The work required for machining under similar cutting condition increases for the composite when compared to the unreinforced matrix.
- Frictional force is seen to increase in the case of the composite and to reduce it cutting conditions need to be optimized.
- Shear strain is minimum under the optimized cutting condition for the composites.
- Material removal rate increases with the depth of cut and speed for the composites when compared to the unreinforced alloy matrix.
- Power consumption and tool wear are higher for composites than that for the matrix alloy.

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