EFFECT OF PROCESS PARAMETERS ON THE GRINDING OF POLYMERIC COMPOSITES

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ABSTRACT

The present paper discusses and compares the results of two similar studies that were carried out in the U.S. and Egypt simultaneously. The objective in both cases was to validate a previously published mathematical model [1-3], which describes the process of grinding polymeric composites by dimensionless numbers.

Cylindrical grinding was carried out by means of a precision lathe and a grinding attachment in the U.S., while an industrial cylindrical grinding machine was employed in the experiments performed in Egypt. This allowed investigating a wide range of values for each process parameter, thus enabling the optimal conditions of grinding of polymeric composites to be determined. Expressing the grinding process quantitatively by non-dimensional numbers provides the flexibility of selecting a value for one of the variables and determining the values of the other variables to yield best ground surface quality and closest tolerances.

1. INTRODUCTION

Fiber-reinforced polymeric composites are currently used for fabricating leisure products such as racing boats, sailing masts, skiing boards, etc. Recently, graphite-epoxy composites have found applications in the manufacturing of construction panel, rockets, and aircraft body such as the new American jet liner 787. Many industries are continuously trying to make use of graphite epoxy composites to replace light weight, high-strength alloys as components in machine construction. A major obstacle is, however, the inability to achieve adequate level of dimensional accuracy and surface quality in precision machining operations of those composites. Many problems are encountered, for example, when grinding graphite-epoxy composites as a result of the structure and properties of this material which are different from those of metals.

The present work is a part of a long-term investigation into the grinding of graphite-epoxy composites, which is aimed at gaining a deeper insight into that process in order to enable optimization of its parameters. It is based on a previously published paper [1], where the grinding process was quantitatively expressed by the following group of non-dimensional numbers:

$$Pi1 = \frac{t}{D} \qquad (1)$$

$$Pi2 = \frac{\cup}{V} \qquad (2)$$

$$Pi3 = \frac{\cup D}{\propto} \qquad (3)$$

Where: t = depth of cut

D = diameter of workpiece

$\cup$ = axial feed rate

V = grinding wheel linear velocity

$\propto$ = thermal diffusivity = $\frac{K}{C_v}$

K = thermal conductivity

C_v= volumetric specific heat = density X specific heat

Since all the above-mentioned members are non-dimensional, either the SI or the English system of units can be used without affecting the values of those numbers. This is indeed another advantage of employing non-dimensional numbers.

2. EXPERMINTS

Cylindrical grinding experiments were carried out on graphite-epoxy composite tubes each was bout 0.15m in length, 0.1m in diameter, and 0.05m in thickness. The fiber-to-epoxy ratio was 70 to 30 by volume and the fibers of the outer layers made an angle of 80-110 degrees with the axis of the tube.

The properties of the fibers and the epoxy were provided by the suppliers, and the properties of the composite used could accordingly be determined by the rule of mixture, and were found to be as follows:

Density = 1.633 kg/m^3

Specific heat = 938 J/kg. K

Coefficient of thermal conductivity = 4.963 W/m.K

Aluminum oxide grinding wheels were used throughout the experiments carried out in both Egypt and the USA. Their designation according to the Standard Marking System was A46-I-8-V32A, and they were produced by Camel Grinding Wheels (CGW) in the USA. Each grinding wheel was subjected to dressing using a diamond tool every time before using it in a grinding operation, in order to remove the dulled layers and to keep it always sharp. No coolant was employed during the grinding operations in order not to eliminate the effect of heat retention at the surface layer of the workpiece.

An industrial cylindrical grinding machine was employed for the experiments carried out in Egypt. Three different values for the R.P.M. of the workpiece, namely 22, 70, and 130 were used. The depth of cut was 0.01mm and 0.02mm, while the axial feed rate was 3.5m/min and 6.5m/min. The linear speed of the periphery of the grinding wheel was 1550 and 1850m/min.

The cylindrical grinding experiments in the USA were carried out on a precision GHB-134 gear head lathe made by JET equipment and tools. The workpiece was firmly held by a split collet (made by Dunham Tool Company) which was in turn chucked. A grinding attachment, with the grinding wheel, was mounted on the carriage of the lathe. The attachment had its own electric motor and a dial indicator was used to ensure that its axis was always parallel to the axis of the lathe. The workpiece rotation was 70 R.P.M. and the axial feed was automatically provided by the carriage, whereas the depth of cut was controlled by the cross-slide.

After each grinding operation, the surface roughness of the workpiece was measured by means of a profilometer (surface roughness measuring gauge). Three measurements were taken and the average of them was considered to be a quantitative indication of the quality of the surface.

3. RESULTS AND DISCUSSION

Figures 1 and 2 indicate the variation of the surface roughness of the ground composite tube versus the R.P.M. of the workpiece when employing the industrial cylindrical grinding machine for two values of axial feed rate, namely 3.5 m/min and 6.5 m/min respectively. In each figure, two graphs are shown corresponding to depths of cut of 0.01 mm and 0.02 mm respectively. It can be seen from both figures that the R.P.M. or, in other words, the linear velocity of the workpiece “v” has a marked effect on the surface roughness. In fact, the results indicate that its effect is far more than that of the linear speed of the grinding wheel. But since it was not considered among the variables affecting the process when the Pi theorem was applied, it has to replace V in the $Pi2$ expression, as follows

$$Pi2 = \frac{v}{U} = \frac{\pi DN}{U} \qquad (4)$$

Where N is the R.P.M of the workpiece.

In order to understand the physical meaning of the above-mentioned non-dimensional number, we have to bear in mind that the tool path on the surface of the workpiece is actually a helix. The angle which the tangent to that helix makes with the axis of the workpiece is called the helix angle, say $\emptyset$. It is not difficult now to see that $\emptyset$ is a function of $Pi2$ and the relationship can be given by the following equation:

$$tan\,\emptyset = \frac{v}{U} = Pi2 \qquad (5)$$

Again the direction of the linear velocity of the grinding wheel relative to the workpiece (which is the direction of cutting) is always normal to the helix of the tool path. In other words, the value of $Pi2$ determine the cutting direction relative to the tube axis and accordingly relative to the direction of reinforcing fibers. This explains what can be observed in Figures 1 and 2, where for the same depth of cut 0.02 mm and same workpiece R.P.M., the surface roughness of the ground surface was lower when the axial feed was 6.5 m/min than when it was only 3.5 m/min. In the first case, cutting took place normal to the direction of fibers, a condition that yields the best surface finish according to other researchers [4, 5].

It can be also seen from Figures 1 and 2 that the depth of cut has an effect on the surface roughness of the ground workpiece when higher values of axial feeds are used. In other words it is influenced by the product of U and t. the two non-dimensional numbers $Pi1$ and $Pi3$ can be mathematically manipulated to reflect this finding.

We can introduce $Pi5 = Pi3/Pi1$

$$Pi5 = \frac{\cup D}{\alpha} . \frac{t}{D} = \frac{\cup t}{\alpha} \qquad (6)$$

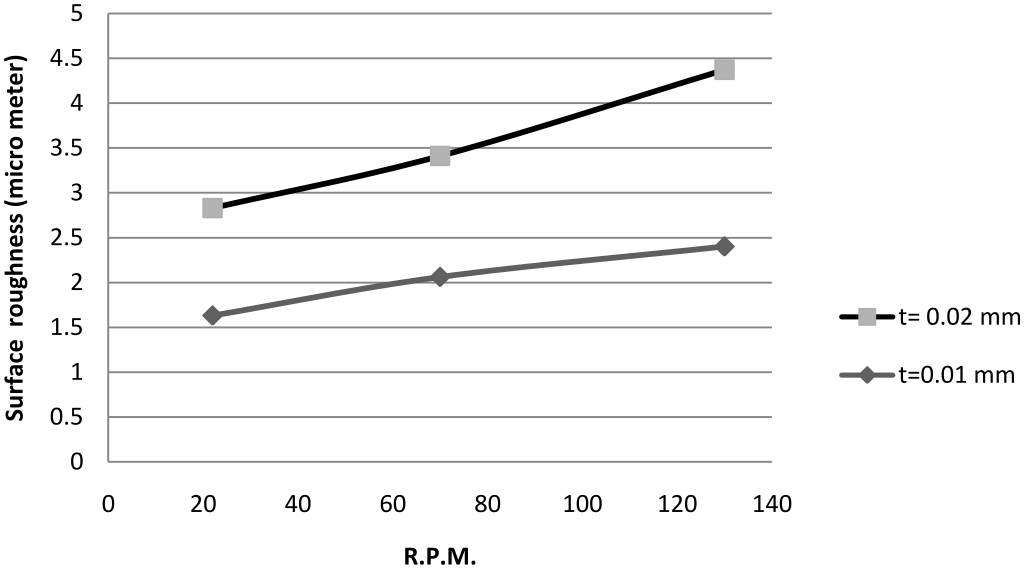

Figure 1: Surface rughness versus R.P.M. (U = 3.5 m/min)

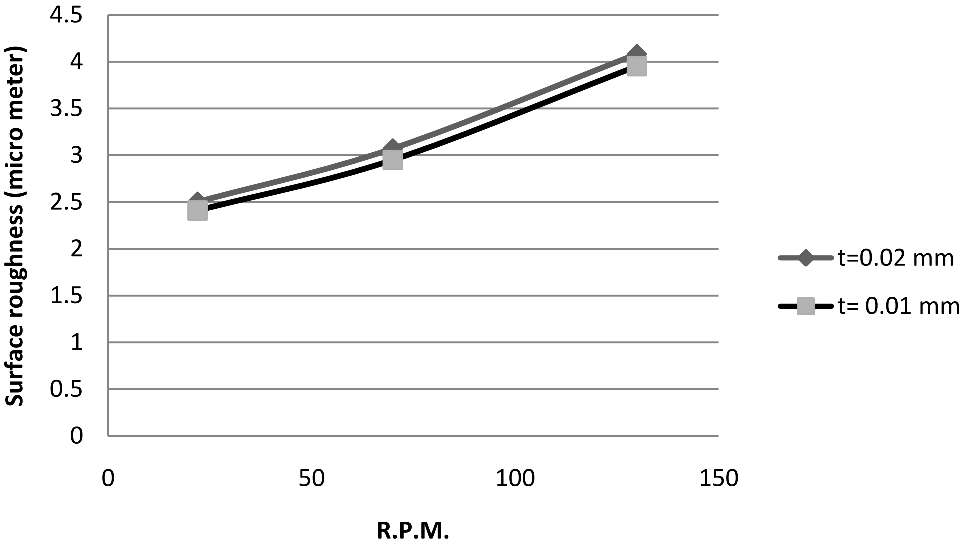

Figure 2: Surface roughness versus R.P.M. (U = 6.5 m/min)

The numerator is an indication of the material removal rate when the diameter of the workpiece is kept constant. It is also an indication of the rate of thermal energy dissipated due to machining for a specific material (and depends on its specific energy). The denominator is the ability of the material to diffuse thermal energy. $Pi5$ must be kept below a certain value to be determined experimentally. In the current research, $Pi5$ was always very low, and far from that limit.

Figure 3 indicates the variation of surface roughness with $Pi3$ for experiments performed in the U.S., when the depth of cut was 0.05 inch (1.27 mm). It can be seen from the figure that there is an optimum value for $Pi3$ that yields the lowest value of surface roughness i.e. the highest surface quality. Graphs corresponding to other depths of cut (not shown here) have identical trend. In order to interpret that graph, we have to bear in mind that $Pi3$ is a direct function of U (the axial feed). That graph can, therefore, be considered as the surface roughness versus the axial feed U. There is an optimum value for the axial feed, and evidently, it depends on the R.P.M. of the workpiece as given in $Pi2$. The later would give optimum results

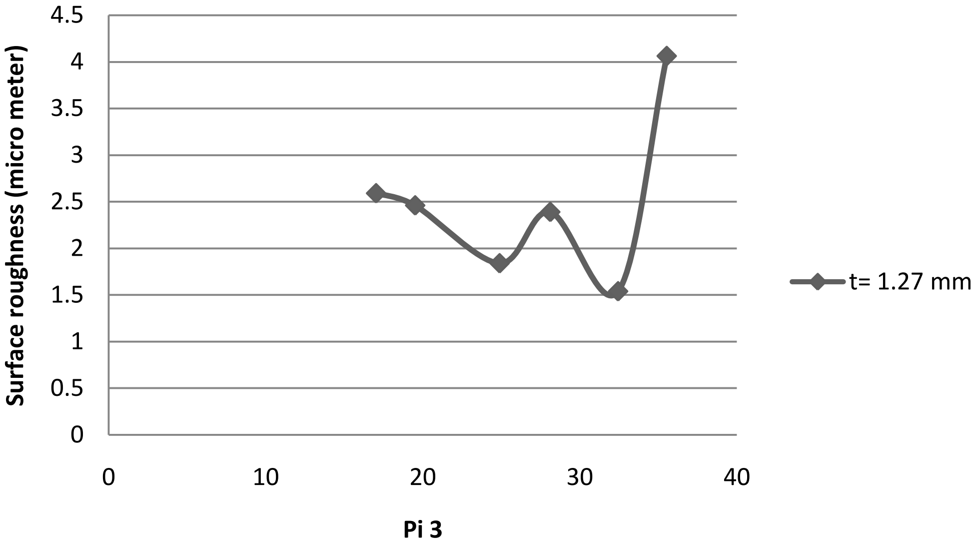

Figure 3: Variation of surface roughness with Pi 3

if the angle of the tool path helix is similar to that which the reinforcing fibers make with the axis of the tube, as previously explained. In the current work, the fibers of the outer layers made an angle of 80 to 110 degrees with the axis of the tube. The helix angle corresponding to the optimum values of $Pi3$ and U is 89 degrees. This is evidently a compromise between the above-mentioned two angles.

4. CONCLUSION

1) The analysis of the experimental results enabled modifying $Pi2$ so as to include the effect of the linear velocity of the workpiece.
2) The current Pi is TAN of the angle which the tool path helix makes with the axis of the tube. Best results are obtained when that angle is equal to the angel of inclination of the fibers to the axis of the tube. In that case, cutting would be normal to the fibers.
3) There is a hyperbolic relationship between U and t , i.e. when t is increased U must be decreased. The constraint established by $Pi2$ must, however, be met first.

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