Machinability Study of Particle Reinforced Aluminium Metal Matrix Composites

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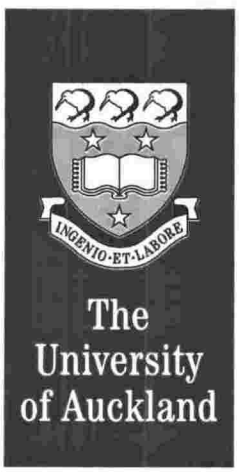

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REVISED ABSTRACT

(For electronic record only)

In this thesis, machinability of particle-reinforced aluminium metal matrix composites, Comral-85 and *DURALCAN*™, has been studied. Continuous turning of round composite bars, using polycrystalline diamond (PCD) inserts has been selected as the test method. The test conditions included cutting speeds varying from 75 to 700m/min and feed rates from 0.1 to 0.4 mm/rev with constant depth of cut of 0.5 mm.

The main wear mechanism of machining these Al MMC materials is abrasion by the reinforcing particles and the primary type of tool wear is flank wear. Linear regression techniques has been used to derive Taylor equations to describe the tool performance. The results show that the time required to reach the tool wear limit decreases with increased speed and feed rate. However, the volume of material removed before reaching the wear limit actually increases with the higher feed rate. This apparent anomaly has been reconciled in a modified Taylor equation.

As for surface finish, the feed rate is found to be a more dominant factor than cutting speed. The higher the feed rate is, the worse the surface finish becomes. The surface finish is found to improve with tool wear at early stage because of the increase of tool nose radius; after that it starts deteriorating as a consequence of excessive tool wear.

The change of feed rate is also more influential on the variation of machining forces than that of cutting speed. Using the same regression techniques, the general machining force-tool wear equations are derived. The results show that the equation derived from the feed force is better suited to monitor tool wear than that derived from the cutting force. The general relationship between tool wear and power consumption has also been established.

The chip forming mechanism while machining *DURALCAN*™ MMC has also been studied by using an explosive charged "quick-stop" device. The primary chip forming mechanism involves the initiation of cracks due to the high shear stress, followed by the decohesion of particles and matrix material within the chip due to the stress concentration on the edge of the particles. The crack propagation is enhanced through the microvoid coalescence within matrix material. The fracture and the sliding of material then follow to form semi-continuous "saw-toothed" chips.

ABSTRACT

With the increasing usage of metal matrix composites (MMCs) in various applications such as aerospace, automotive and sports related industries, the machining of such materials has become a very important subject to study. Owing to the addition of reinforcing materials which are normally harder and stiffer, the machining becomes significantly more difficult than that of conventional monolithic materials. Among many types of MMCs, the most popular types are aluminium alloys reinforced with ceramic particles since they cost less but provide favourable properties with only a minimum increase in density over the base alloy. These properties include high specific strength/stiffness, wear and corrosion resistance and fatigue resistance, etc.. In this thesis, machinability of particle-reinforced aluminium metal matrix composites has been studied.

Continuous turning of round composite bars, made from Comral-85 and *DURALCAN*™, using polycrystalline diamond (PCD) inserts, with average diamond size of 25-μm, has been selected as the test method. The test conditions included cutting speeds varying from 75 to 700m/min and feed rates from 0.1 to 0.4 mm/rev while the depth of cut was kept constant at 0.5 mm. The four machinability related aspects, namely tool wear, surface finish, machining forces and power consumption, are constantly monitored during the machining process. The nature of chips formed is also recorded for further analysis.

It has been confirmed that the main wear mechanism of machining particulate reinforced aluminium MMC materials is abrasion by the reinforcing particles and the primary type of tool wear is flank wear. The performance of the tools is, therefore, based on the development of flank wear, which has been monitored by optical and scanning electron microscopy. The tool life criterion for machining Comral-85 is 0.3-mm flank wear, whereas for machining of *DURALCAN*™ composite, the tool life criterion is up to flank wear of 0.25 mm. The tool life data have been analysed using linear regression techniques and a traditional Taylor model involving cutting speed only has been established for this material. A general form of the Taylor equation has also been developed by regression methods to describe the tool performance. The results show that the time required to reach the tool wear limit decreases with increased speed and feed rate. However, the volume of material removed before reaching the wear limit actually

increases with the higher feed rate. This apparent anomaly has been reconciled by rewriting the Taylor equation in a modified form.

In the aspect of surface finish, it has been found that the feed rate is a more dominant factor than cutting speed. The higher the feed rate is, the worse the surface finish becomes. Therefore, in the selection of machining parameters, after taking into account of the surface finish allowed, the feed rate should be as high as possible to achieve the maximum material volume removal. On the other hand, the change of surface roughness while machining at a constant speed is mainly due to the progress of tool wear. The surface finish is found to improve with tool wear before the flank wear reaches around 0.15 mm because of the rounding of tool nose radius; after that it starts deteriorating as a consequence of excessive tool wear.

Similar to surface finish, the change of feed rate is more influential on the variation of machining forces than that of cutting speed. Nevertheless, the change of cutting speed has a resembling effect on machining forces as that on the growth of tool wear. Consequently, the recorded machining force data against tool wear have also been analysed using the same regression techniques to derive the general machining force-tool wear equations. The derived tool wear-machining force equation can be used to indirectly monitor the development of tool wear during machining operation for deciding the tool life. The results show that the equation derived from the feed force data is better suited to monitor tool wear than the one derived from the cutting force.

As the result of the direct relationship between cutting force and power consumption, the power consumption data have also been regressively analysed. The general relationship between tool wear and power consumption has been established. Even though this relationship is a more conservative approach, it can be the other way of indirectly monitoring the tool wear growth with sufficient accuracy.

Lastly, the chip forming mechanism while machining *DURALCAN*^{TM} composite material has also been studied by using an explosive charged "quick-stop" device. During the chip breaking process, the primary chip forming mechanism involves the initiation of cracks from the outer free surface of the chip due to the high shear stress. Meanwhile, some small voids are formed by the decohesion of particles and matrix material within the chip due to the stress concentration on the edge of the particles. The crack propagation is enhanced through the microvoid coalescence

within matrix material from one particle to the other along the shear plane. The fracture and the sliding of material then follow to form semi-continuous "saw-toothed" chips. The average shear angle has been found to increase slightly with the increasing cutting speed, hence, thinner chips are formed and easily broken into smaller pieces with higher cutting speeds. However, for the formation of "saw-toothed" chip, the shear angle varies during chip forming and the variation is more significant with the increasing cutting speed.

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