Ductile Regime Machining of 45S5 Bioglass

THESIS SUBMITTED IN PARTIAL FULFILLMENT

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by

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CHAPTER 8

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

This chapter represents the present research work's conclusions and suggestions for future work.

8.1 Work conducted in this research

In this research work, bulk thermal softening is chosen as the primary stage to reduce the hardness of 45S5 bioglass to achieve the research objectives of the thesis. In order to heat the samples, a portable heating system with overall measurements of 105 x 150 x 53 mm^3 has been designed and developed successfully. This can be used to heat the samples up to 1000 °C in a variety of applications, including grinding, indentation testing, machining ceramic samples on a VMC, and scratch testing. With the right temperature distribution on the surface, different average temperatures on the sample surface of the heat plate can be produced. At various temperatures, heated samples underwent scratch and indentation testing. The scratch tests then produced data on the normal load, traction force, coefficient of friction, and scratch images under various scratch circumstances. The fracture toughness as it relates to temperature fluctuations was determined via indentation tests. While performing the scratch tests, the reduction in traction force at an elevated temperature is a clear indication of the reduction in cutting force if the material undergoes the machining process at an elevated temperature. Additionally, the ductile-brittle transition zone is located by analysing the scratch images, and the depth of the scratch at the transition zone—often referred to as the critical depth of cut for enhanced machinability—was measured. Following that, a mathematical model has been put forth to determine the critical depth of cut for 45S5 bioglass at various temperatures.

Additionally, during the scratching operation, the AE signals are recorded using the AE sensors. These signals were processed using wavelet analysis and then connected with the scratch process since they exhibit relatively few observable fluctuations during the procedure. These tests helped researchers understand how the 45S5 bioglass behaves when scratched at various temperatures.

8.2 Conclusions

Based on investigations done in the present research work, the following are the conclusions drawn from the thesis:

- The developed portable heating setup can heat the samples up to 700 °C with an appropriate temperature distribution on the sample surface. The maximum standard deviation of temperature on the working area of the sample top surface, along L and along B is 5.6%, 3.6% and 3.1%, an appropriate range for experiments. With the use of this set-up, the average value of thermal conductivity of 45S5 bioglass is found to be 1.16 W/m-K. Due to its portability, simplicity of use, and ability to pre-heat the materials, this system is extremely useful in the machining and testing of hard and brittle materials.
- At 27°C, 210°C, and 420°C, 45 scratch tests were successfully conducted. The scratch speeds used were 2 mm/s, 1 mm/s, and 0.5 mm/s. At a constant loading rate of 0.2 N/mm, the usual load ranges for the studies were 20–21 N, 21–22 N, 22–23 N, 23–24 N, and 24–25 N. In keeping with that, it is effectively seen that the coefficient of friction and traction load are decreasing up to 420 °C.
- On 45S5 bioglass samples, six sets of scratches were made at a speed of 1 mm/s and temperatures of 27, 100, 250, 400, 550, and 700 °C in order to analyze the ductile-brittle transition zone. The sample is subjected to a ramp load of 10 to 20 N with a 5 mm scratch length. Five sets of hardness tests are reportedly carried

out at sample temperatures of 27 °C, 100 °C, 250 °C, 400 °C, and 550 °C. Lower traction forces during the scratch test due to the increased temperature suggest enhanced machinability for fragile materials at higher temperatures. Elevated temperature thus caused the material to have lesser hardness as well as lower critical load during scratching.

- It has been proven beyond a reasonable doubt that higher temperatures result in higher critical DOC, which increases MRR, and ductile-brittle transmission at relatively lower normal load. The fracture toughness (K_{ICt}) at temperature t is given in Equation (6.4). Apparently, the elastic modulus (E_t), hardness (H_t) and crack length (C_t) is calculated from Equation (6.6), (6.7) and (6.8) respectively. Further, these values are used to calculate the critical DOC (d_{ct}) at temperature with the help of Equation (6.5) and the value of the proportionality constant at temperature t is given in Equation (6.9). Therefore, Equation (6.5) represents the modified Bifano model for the determination of critical depth of cut at elevated temperature for 45S5 bioglass. Through this research, it is more likely that samples of 45S5 bioglass and other ceramic materials will be easier to machine at higher temperatures (up to 550°C).
- The application of AE sensor has been carried out. The samples of 45S5 bioglass have undergone nine sets of scratches at speeds of 2 mm/s, 1 mm/s, and 0.5 mm/s at temperatures of 27 °C, 210 °C, and 420 °C. The sample is subjected to a ramp load of 20–21 N with a 5 mm scratch length. The AE signals are eventually recorded, and a 5 level haar wavelet analysis is carried out.
- The continuous trend regarding temperature is not seen in the standard deviation and mean absolute deviation for APK values for the fifth level of decomposition. The standard deviation and mean absolute deviation for the ASL values for the

fifth level of decomposition are likewise discovered to demonstrate a continuous trend with regard to temperature, suggesting that signal responses are growing as temperature rises. The analysis of traction force plots, SEM pictures, and contour profiles of scratches led to the conclusion that the higher temperature resulted in reduced traction force and greater depth of cut at the same normal loads. Additionally, the temperature increases for both APK and ASL values implicated an increase in the mean values of processed signals for both APK and ASL values.

- It appears that increased scratch speeds, at all temperatures, lead to a reduction in lateral fracture development, improving machinability. It has been conclusively demonstrated that machining in the ductile regime and at higher temperatures (up to 700 °C) result in deeper cuts with a larger MRR. As a result, it is an excellent method to check the condition of machine tools for lateral crack-free scratching and ductile regime machining. Using an AE sensor in conjunction with wavelet analysis, this study expands the possibility for enhanced machinability characteristics for 45S5 bioglass and other ceramic materials at high temperatures.

8.3 Suggestions for future work

The present research work has a vast scope for future work. Following are the suggestions for future work related to this research:

- The machinability aspects of different ceramic materials can be studied with the present proposed procedure. While this study is yet to explore its aspects above 700 °C of sample surface temperature. For this purpose, the high-temperature setups are required to be fabricated where the body of the heating setup should be made of a high temperature sustainable material.

- The critical DOC values for 45S5 bioglass are yet to be explored at different scratch speeds as well as with different types of scratch probes. The possible probes that can be used for the experiments are Knoop, Vickers, Berkovich etc.
- The application of AE can be performed at higher temperatures to detect the ductile-brittle transition and the corresponding critical DOC. The possible approach is shown in Figure 8.1. A process model as well as a reference model for the cutting operation can be generated which will be generated on the basis of cutting parameters, temperature, and AE signals. Hence, algorithms for change in parameters can generate the adaptive control law for the process. While the operations, if there are any changes in the process models, they will be compared with the reference mode and these changes can be compensated with adaptive control laws. Hence, we will be able to control the ongoing operation for better machinability.

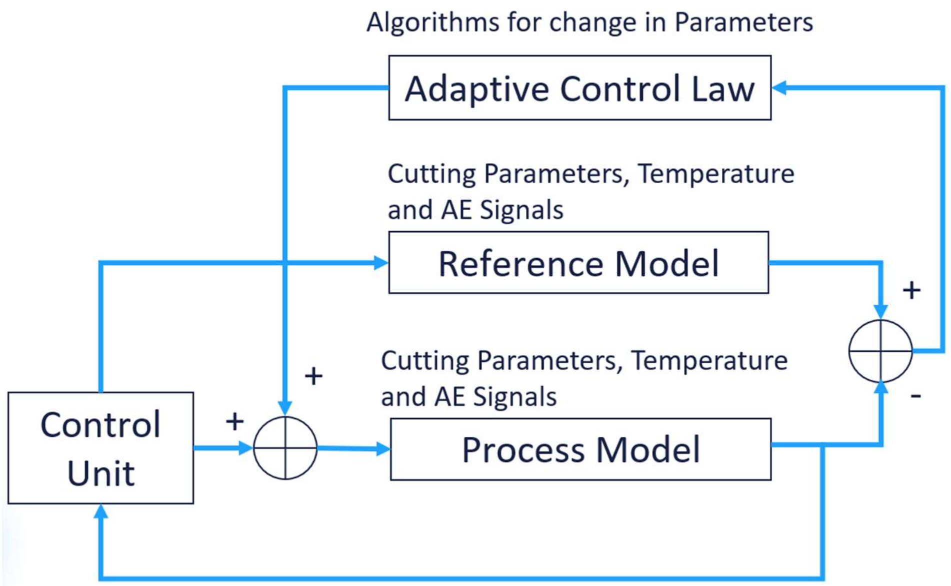

Figure 8.1: Use of AE signals for in-line monitoring and control

- The present research work is not limited to the scratch test only. It can also be carried out on milling, grinding, drilling, turning, etc. This portable setup is useful to be mounted on these machining stations. Using the same approach, the machinability study is possible to carry out on these processes.

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