CHAPTER 5

STUDY OF TRACTION FORCES AT ELEVATED TEMPERATURES DURING MICRO SCRATCH TESTS ON 45S5 BIOGLASS

This chapter describes the study of traction forces at elevated temperatures during micro scratch tests on 45S5 bioglass. The traction forces at different temperatures are compared during scratch tests. The study also expanded to different scratch speeds.

5.1 Operating parameters

Table 5.1: Operating parameters during the scratch test

Temp. (℃)	Load Type	Load Range (N)	Start Load (N)	Loading Rate (N/mm)	Stroke (mm)	Scratch Speed (mm/sec)	Scratch Offset (mm)
27 210 420	Ramp	20-200	20 21 22 23 24	0.2	5	0.5 1 2	1

Table 5.1 shows the operating parameters for the elucidated experiments. The three average temperature values selected to perform scratch tests are 27 ℃, 210 ℃ and 420 ℃. The scratch tester can perform scratch tests at constant load as well as at ramp load. Although the machine has two load cells, one of 0-20 N and the other of 20-200 N, the 20-200 N load cell is selected for the experiments. Additionally, the ramp load is selected to perform the experiments with the loading rate of 0.2 N/mm while the stroke length is kept at 5 mm and the starting load will rise by 1 N at the end of the scratch of 5 mm length. The current loading head starts with the normal load of 20 N. During the experimentation, it was observed that the scratches made with more than 25 N of normal load are full of cracks. Based on the above observation, the experimentation is performed between 20 N and 25 N of normal load. The machine had the least count of 1 N for the input in normal load. Therefore, five starting loads are selected as 20 N, 21 N, 22 N, 23

N and 24 N, so the total load range between 20 N and 25 N will be covered during tests. The offsets between any two scratches are kept constant at 1 mm. Three scratch speeds are selected at every combination to perform the experiments. These scratch speeds are 0.5 mm/s, 1 mm/s and 2 mm/s.

5.2 Experimental procedure

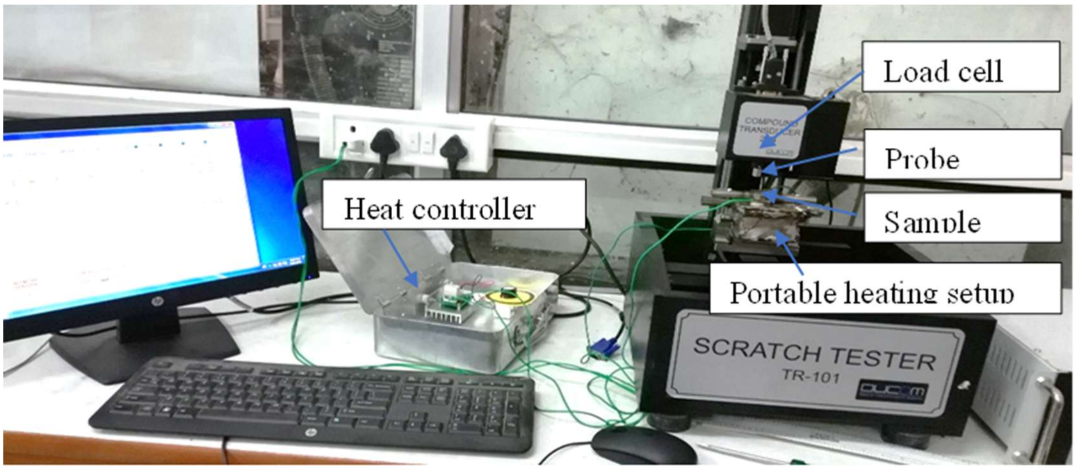

Figure 5.1: Image of experimentation

The sample is mounted on the portable heating setup and this assembly is mounted on a scratch tester as discussed previously. Figure 5.1 shows the image of experimentation. Whereas, Figure 5.2 shows the workpiece image in the experimental condition.

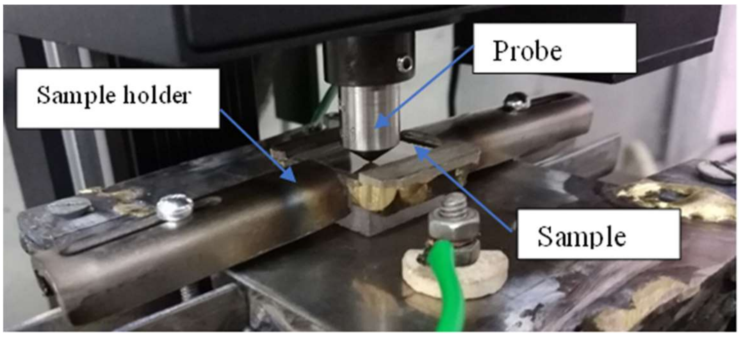

Figure 5.2: Workpiece image in the experimental condition

It was observed that there is a lot of thermal cracking at a fast-heating rate due to a sudden high temperature gradient between the sample's heated and non-heated zones. This high temperature gradient induces high thermal stresses. Therefore, the heating rate of the sample is kept at less than 10 °C per minute to avoid thermal cracking in the samples. The desired temperature is achieved with the help of a heat controller and the steady state is observed for 10 min as the minimum time span. This ensures the least temperature variation during the scratch tests at desired temperatures. Additionally, the reading of the temperature has been observed continuously during scratch tests and made sure that the temperature is in the range of ± 5 °C from the desired temperature value. In total, a set of 45 scratch conditions are performed and allocated a specific number as shown in Table 5.2. Each of the scratch conditions is repeated three times. The best response is chosen based on visual observation. During this observation, the graph is analyzed for any sudden trend change or any sudden change in values of traction forces. These uncertain changes are caused due to defects available in the cast samples. Therefore, the graph with minimum uncertain changes in trends and traction force is selected for further analysis.

Table 5.2: Table of experiments indicating different scratch numbers during a set of 45 scratch conditions

Start Load (N)	**Scratch Speed (mm/ sec)**	**Scratch numbers according to the different temperatures**					
		Sample No.	27 °C	Sample No.	210 °C	Sample No.	420 °C
20	2	1	1.1	3	3.1	5	5.1
21	2	1	1.2	3	3.2	5	5.2
22	2	1	1.3	3	3.3	5	5.3
23	2	1	1.4	3	3.4	5	5.4
24	2	1	1.5	3	3.5	5	5.5
20	1	1	1.6	3	3.6	5	5.6
21	1	1	1.7	3	3.7	5	5.7
22	1	1	1.8	3	3.8	5	5.8
23	1	2	2.1	4	4.1	6	6.1
24	1	2	2.2	4	4.2	6	6.2
20	0.5	2	2.3	4	4.3	6	6.3
21	0.5	2	2.4	4	4.4	6	6.4
22	0.5	2	2.5	4	4.5	6	6.5
23	0.5	2	2.6	4	4.6	6	8.6
24	0.5	2	2.7	4	4.7	6	6.7

5.3 Results and discussion

Scratch tests were performed as shown in Table 5.2. After performing the mentioned tests, the graphs of different starting loads are clubbed together to reduce the number of graphs. So, the complete range of 20 N to 25 N of starting normal load is plotted on a single graph concerning different temperatures as shown in Figure 5.3. Here the traction force corresponding to the given scratch condition is obtained through the inbuilt force sensor. The coefficient of friction is obtained through the ratio of traction force and normal force

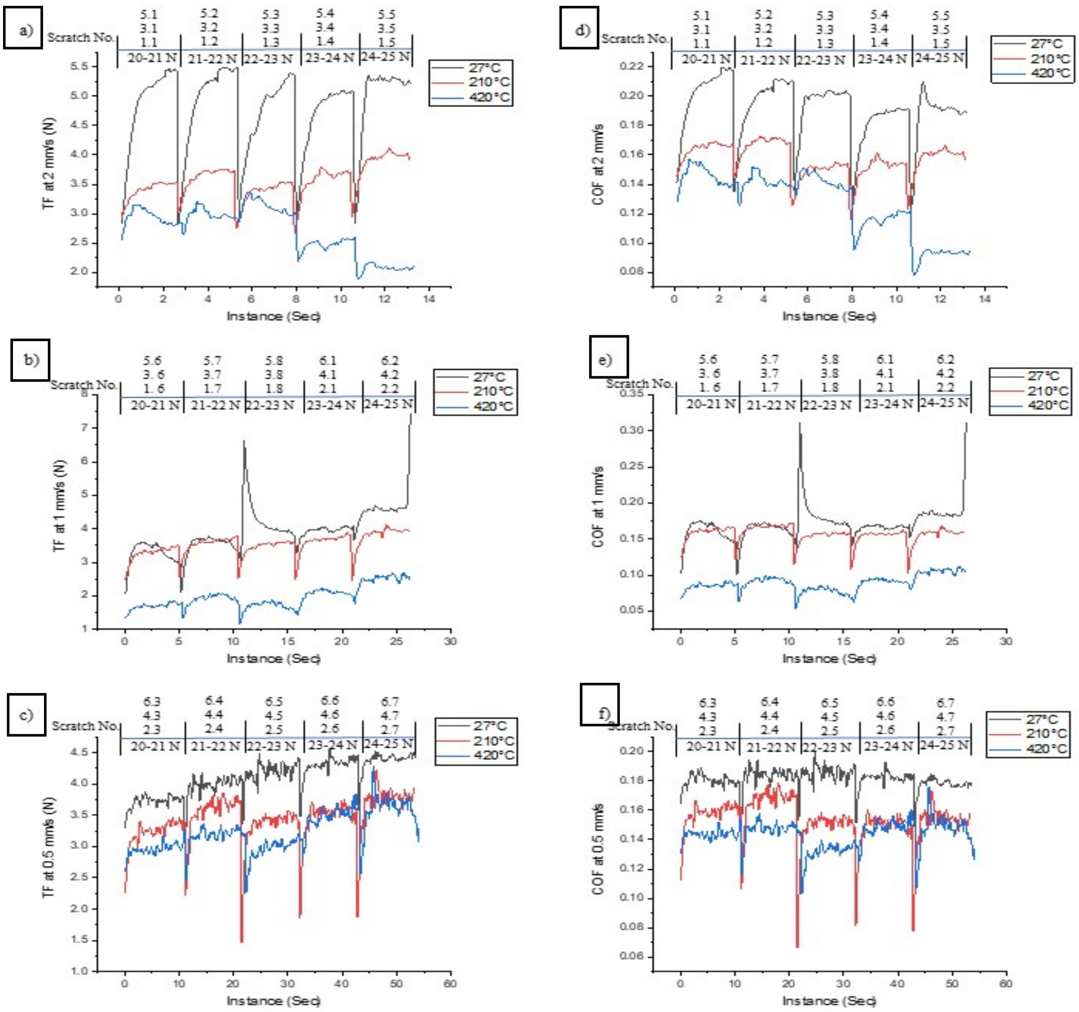

Figure 5.3:Comparative plots for traction force and coefficient of friction at different temperatures (27℃, 210℃ and 420℃) during scratch tests- a) Traction force at scratch speed of 2mm/s, b) Traction force at scratch speed of 1mm/s, c) Traction force at scratch speed of 0.5mm/s, d) Coefficient of friction at scratch speed of 2mm/s, e) Coefficient of friction at scratch speed of 1mm/s, f)Plot for coefficient of friction at scratch speed of 0.5mm/s.

at any instance of time. One can see in Figure 5.3 that, the scratch numbers are mentioned above the load ranges of the upper portion of every graph. Five graphs are plotted from left to right exactly below the mentioned load ranges. Consequently, the different responses at different temperatures are plotted under the mentioned load ranges with different colours. The X-axis scale variation represents the instance time of the scratch and the Y-axis variation represents the variation of the traction force and the coefficient of friction. The same pattern is followed for every graph shown in Figure 5.3. It shows the comparative plots for traction force and coefficient of friction at different temperatures (27 °C, 210 °C and 420 °C) during scratch tests whereas, Figure 5.3(a) shows the plot for traction force at scratch speed of 2 mm/s, Figure 5.3(b) shows the plot for traction force at scratch speed of 1mm/s, Figure 5.3(c) shows the plot for traction force at scratch speed of 0.5 mm/s, Figure 5.3(d) shows the plot for coefficient of friction at scratch speed of 2 mm/s, Figure 5.3(e) shows the plot for coefficient of friction at scratch speed of 1 mm/s and Figure 5.3(f) shows the plot for coefficient of friction at scratch speed of 0.5 mm/s.

It is observed from Figure 5.3 that the traction forces as well as the coefficient of friction during scratch tests are decreasing with the increase in sample temperature. This phenomenon repeats even at different scratch speeds as shown in Figure 5.3. The higher speed results in a higher strain rate. Eventually, the higher strain rate results in fast surface

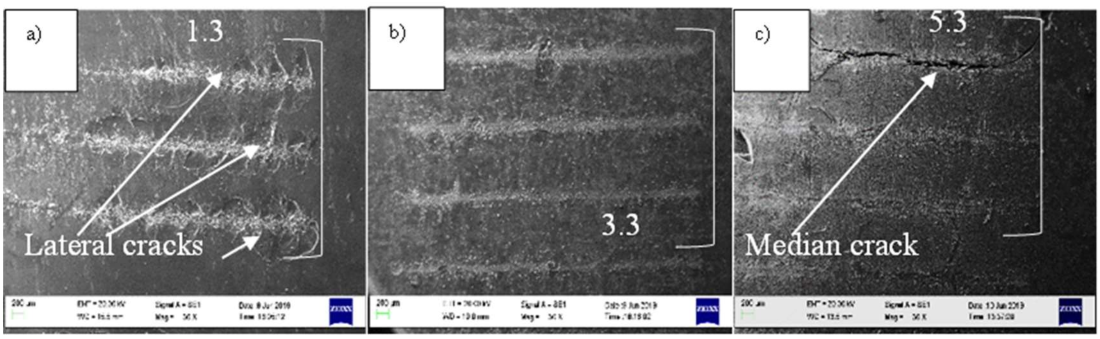

Figure 5.4: a) SEM image for scratch no. 5.3, b) SEM image for scratch no. 3.3 and c)SEM image for scratch no. 1.3

interaction between the probe and the sample surface. Due to the fast surface interaction, the traction force increases prominently. This increase in traction forces and coefficient of friction at high speed can lead to better machinability of hard-to-machine materials.

Figure 5.4 shows the three typical SEM images Figure 5.4(a), Figure 5.4(b), and Figure 5.4(c) of scratch sets 5.3, 3.3 and 1.3 respectively which are at 27 °C, 210 °C and 420 °C of surface temperatures respectively. The scratch speed during these scratches is 2 mm/s and the load range was 22-23N. One can see in Figure 5.4(a) that more lateral cracks are present around the scratch path at a temperature of 420 °C. It is also observed from Figure 5.4(b) that very few lateral cracks present at a temperature of 210°C as compared to the scratch at 420 °C. Subsequently, the scratch mark is less visible in Figure 5.4(b) as compared to Figure 5.4(a). One can also see in Figure 5.4(c) that the lateral cracks are not visible at 27 °C but the scratch mark visibility is also very less as compared to Figure 5.4(a) and Figure 5.4(b). The rise in temperature leads to lower material hardness. The lower hardness will result in less traction force and more penetration of the probe into the material. The less visibility of scratch indicates less surface penetration by the scratching probe. This visual comparison is a positive indication of a reduction in traction forces and coefficient of friction during the scratch. The images indicate the deeper penetration at the same load with the rise in temperature but lateral cracks are increasing. Overall, the reduction in traction force and coefficient of friction may lead to better machinability.

5.4 Summary

A set of 45 scratch tests were performed successfully at 27 °C, 210 °C and 420 °C as well as the scratch speeds were taken as 2 mm/sec, 1 mm/sec and 0.5 mm/sec. The normal load ranges for the experiments were 20-21 N, 21-22 N, 22-23 N, 23-24N and 24-25 N at a ramp loading rate of 0.2 N/mm. In continuation of that, different comparative graphs are plotted and it is successfully observed that traction load and coefficient of friction are reduced at elevated temperatures. These results are continuous even at different scratch speeds as shown in Figure 5.3. These results are a clear indication of the reduction of the hardness of the material with an increase in temperature. This elucidation leads to raising the bar of machinability aspects of ceramic materials. It is, therefore, established that this process can be of great utility in existing machining processes and for testing the feasibility of machining difficult-to-machine materials.