Surface Roughness and Impacts between Golf Balls and the Face of a Golf Club Head

A Major Qualifying Project Report

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Abstract

This project evaluates the impact of correlating surface roughness between golf club head and golf ball. A repeatable test was created by dropping golf ball on three stainless steel plates. I used the Olympus LEXT to test the surface roughness of the plates. The dynamometer and LabVIEW program were used to record the force during impact. The coefficient of friction was calculated by both normal and transversal forces. The goal of this project is to study different surface roughness and to evaluate their performances as a golf club head surface.

1. Introduction

Golf is a club game and ball sport in which players could use various clubs to hit balls into a series of holes on a course in as few strokes as possible. The surface roughness of clubs could is a huge factor in professional games. By knowing coefficient of friction of the clubs helps the ball getting closer to the landing point.

1.1 Objective

The objective of this project is to determine a correlation between coefficient of friction (COF) and the surface roughness between a golf ball and a golf club head surface. This project will involve designing a testing procedure to determine the COF and also to test the surface roughness of the testing plates.

1.2 Rationale

In professional golf games, the quality of golf club head could affect the game result. By better understand the COF and the surface roughness of golf club head would improve the quality of golf clubs in the future. This could also help the golfers' performance in their matches.

1.3 State-of-the-Art

1.3.1 Ping-Pong Ball Study

Impact behavior of ping-pong balls has been studied by University of Sydney. The experiment was done by dropping a ping-pong ball by hand at speeds up to about 10m/s normally on a force plate. A 600 fps camera was used to measure the incident speed and rebound speed of ping-pong ball. Force measured from the force plate versus time elapsed is plotted to graphs in order to obtain properties of impact (Cross 2014).

1.3.2 Golf Ball Dynamic Behavior due to Impact

Researchers have been studying the impact behavior of golf balls including contact force and time spin rate as a function of impact velocity. Experimenting by launching a golf ball horizontally to an oblique surface has previously been done. As inbound ball velocity increases, the average angular velocity of the ball will increase after impact. If a relatively smooth surface compare to rough surface is used as an impact surface, the angular velocity after impact will decrease (Arakawa et al. 2007).

1.3.3 USGA Regulation

USGA regulation state the following: “the whole of the impact area must be of the same material.” The regulations also indicate that “face treatments have may be applied (i.e. grooves, sandblasting, etc.).” Though extreme alterations to the material is not permitted, the USGA has many exceptions to allow various surface finishes.

1.3.4 Friction Effect on Golf Club

The effect on golf performance of friction between the hitting surface and the ball is closely related to the skills used in the game. Essentially, the game of golf can be classed into two major skills, the long game and the short game. Whilst the long game involves such skills as driving a golf ball as far as possible from the tee and hutting a golf ball straight long distances from fairway, the short game involves kills such as pitching a golf ball from a location near the green and putting the golf ball into the hole on the green.

Generally, high friction between the hitting surface and the ball for long shots (especially for driving) is undesirable. This is mainly because tolerance for mis-hits on the sweet spot decreases with increasing friction between the hitting surface and the ball owing to the increased likelihood of hooking or slicing a given show. Thus, the distance that the golf ball can fly would be reduced because the energy is wasted on the fast side-spin of the golf ball and heat generated from the friction. Meanwhile, such undesirable shots also affect directional accuracy. Clearly, low friction between the hitting surface and the golf ball is desirable for long-distance shots. （McLean 2000）

1.3.5 Milled Die Surface Roughness Correlation

In a study on milled die steel surface roughness correlation with steel sheet friction, a team of engineers conducted linear regression analysis of 32 characterization parameters against the surface roughness of milled die. The purpose of performing the analysis was to determine which characterization parameters best relates the friction found in sheet metal forming and the surface roughness of metal dies. The study used the bending under tension test of sample surfaces, a test commonly used when analyzing metal dies, to measure friction. Through the use of linear regression analysis, the study was able to compare the friction measurements against the surface parameters by producing R2 values and was able to determine which parameters were most closely related to the friction found in sheet metal forming. This study exhibits a good example of how a linear regression analysis can be useful in relating factors of surface roughness with friction. The study was able to find that inclinations of a surface roughness are important to consider when analyzing friction in sheet metal forming because of their strong correlation factor. The study also provides a good example of how to understand the linear regression models that the analysis produces to determine which parameters should be considered and which should not be considered (Berglund et al. 2010).

1.4 Approach

To study the relationship between golf ball and golf club head, we will need to find the COF and surface roughness of the testing plates. The work will be completed in three areas: designing a system to measure the normal and transversal forces during the impact, finding the surface roughness properties of three testing plates, and correlating

COF to surface roughness.

When measuring the COF, it is important to measure both the tangential and normal forces. In order to get the force data, a Kistler dynamometer can be capable of quasi-static and dynamic measurements. It is also important to measure both tangential and normal forces simultaneously because they are closely related to each other. The Kistler dynamometer will provide with real time data of both forces and therefore I can use the force data to calculate the COF.

2. Method

2.1 Testing Surfaces

According to the restriction enforced by the United States Golf Association, it is important to select the appropriate materials that would be used for the testing surfaces. Therefore, professionally finished stainless steel plates were obtained from the New England Metals Finishing Company. The three testing surfaces consisted of a 60 grit satin finish, a 220 grit satin finish, and an aluminum oxide finish.

2.2 Surface Roughness Measurement

In this experiment, the microscope used to take the measurements was Olympus LEXT OLS4100. In order to take accurate measurement, the microscope was used at 20x (times magnification). I took three measurements for each surface at different locations because the golf ball would not hit the same place every time.

2.3 Analysis

I used the program Mountains 7 to analyze the measurements. This software could provide many common surface roughness parameters, which are important in our experiment.

After analyzing the measurements, I used Sfrax to characterize the surface. The data I got by using this software could show me the best scale to characterize the surface.

2.3.1 Golf Ball Release

For this experiment, the golf ball is required to be released consistently from the same height, so a 2-meter long plastic pipe was used to be placed straightly next to the testing surface, in order to make sure that each time the golf ball would drop approximately from the same height. This would provide the golf ball with a consistent initial velocity and minimal spin. Therefore, the distance between the releasing point of the golf ball and testing surface is set to be 2-meter. In order to protect the lab equipment, card boards were placed surrounded the dynamometer.

2.3.2 Equipment

I used the Kistler 9267B Dynamometer in order to measure the force during impact and then correlate those results to find out the spin rate and velocity of the golf ball. The three testing surfaces were placed beyond the dynamometer along with a 42° angle and also make it stabilized. The dynamometer needs to connect to the LabVIEW program. According to the graphs getting from the LabVIEW, which could calculate the force of the golf ball hitting the testing surface of X-Z axis. An amplifier and data acquisition system also need to connect to the Kistler dynamometer.

A high speed camera could be helpful in this experiment. However, by considering the weight and the value of the dynamometer, the high speed camera was not used in this experiment and thus the spin rate cannot be calculated. By using the high speed camera, it could clearly show the motion of the golf ball so that it helps to find the spin rate of the golf ball after it hits the testing surface.

Data acquisition device acts as the interface between a computer and signals from the outside world. It primarily functions as a device that digitizes incoming analog signals so that a computer can interpret them. NI USB-6009 was used as data acquisition device. Data acquisition device was connected to dynamometer amplifier and computer. Device was connected to three channels of amplifiers separately, which are X, Y and Z direction voltage generated from the amplifier.

3. Results

3.1 Surface Roughness Data

In order to obtain the detailed surface roughness data, I collected data on parameters from ISO 25178. To compare these three surfaces, I took three measurements for each surface at different locations and measured for seven ISO 25178 surface parameters.

Table 1: ISO 25178 Height Parameters

ISO 25178 Parameter	60 Grit	220 Grit	Aluminum Oxide
Root-Mean Square Height (μm)	10.55	0.953	0.384
Skewness	-0.104	-0.674	-0.119
Kurtosis	2.893	4.417	2.477
Maximum Peak height (μm)	28.533	4.737	1.807
Maximum Pit Height (μm)	26.9	5.76	1.217
Maximum height (μm)	55.433	10.497	3.02
Arithmetic Mean Height (μm)	8.34	0.729	0.0312

Table 2: ISO 25178 F-Test Results (90% Confidence)

F-Test Results	60 Grit & 220 Grit	60 Grit & Aluminum Oxide	220 Grit & Aluminum Oxide
Root-Mean Square Height (μm)	1.831E-04± 1.509E-08	1.045E-01± 4.913E-03	1.009E-05 4.585E-11
Skewness	4.991E-01± 1.002E-01	6.538E-03± 1.924E-05	2.179E-03± 2.136E-06
Kurtosis	4.572E-02± 9.407E-04	8.148E-02± 2.987E-03	7.104E-01± 2.271E-01
Maximum Peak height (μm)	3.754E-02± 6.340E-04	4.215E-01± 7.994E-02	1.016E-02± 4.647E-05
Maximum Pit Height (μm)	9.845E-03± 4.362E-05	6.537E-02± 1.922E-03	3.342E-04± 5.027E-08
Maximum height (μm)	7.058E-03± 2.242E-05	8.994E-03± 3.640E-05	3.200E-05± 4.607E-10
Arithmetic Mean Height (μm)	4.665E-04± 9.794E-08	4.768E-02± 1.022E-03	1.140E-05± 5.843E-11

In order to find the significant difference from these three plates, I used F-test to analyze the data. The F-test statistic is the ratio of the two sample variances squared. By identifying the result of an F-test, we can find the variance between the two surfaces are not significantly different. The further the value is from 1, the stronger the evidence of two populations are distinguishable from each other (Snedecor and Cochran, 1983).

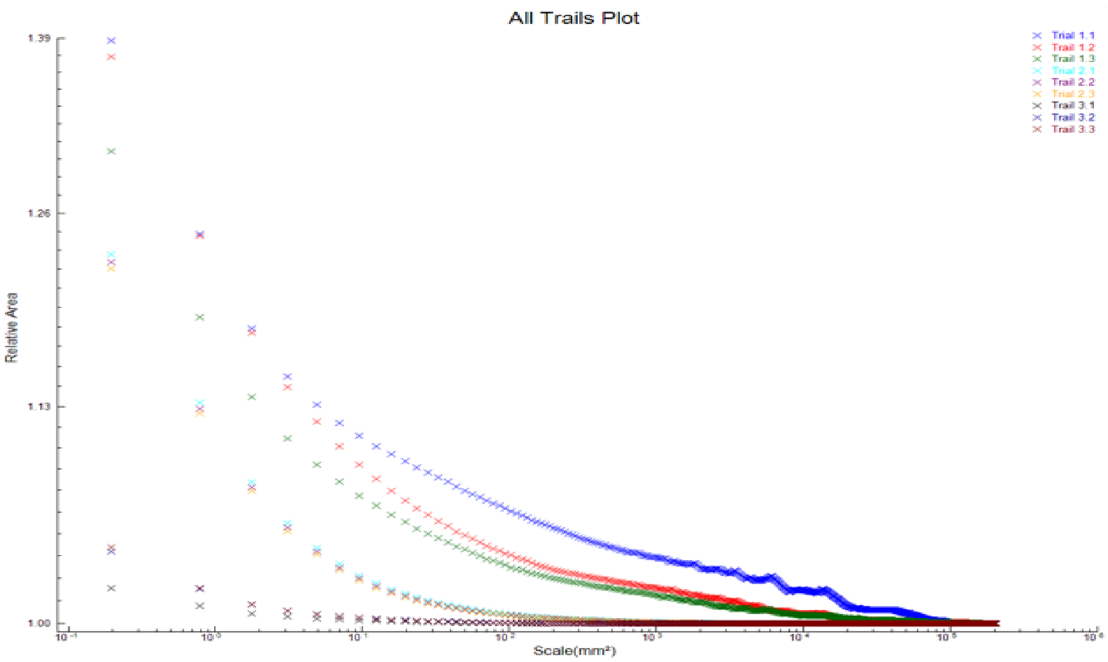

Figure 3: Sfrax File for all Measurements at 20x

These measurements were taken with the 20x lens do show a difference in the surfaces. We can clearly recognize each surface by looking at the curves. This plot shows that the curve of Aluminum Oxide surface runs the smoothest, the 220 grit finish in the middle and 60 grit finish is on the top. Through further testing of the data we hope to be able to correlate this data with COF at the most influential scales.

3.2 Force, Coefficient of Friction and Spin Rate

3.2.1 Transversal and Normal Force

$$Force_{Frictional} = \mu \ Force_{Normal}$$

As the formula above shows, in order to find the COF, we need to find both Normal Force and Transversal Force. To obtain the data, the golf ball was dropping from 2-meter height on three testing surfaces. The testing surfaces, meanwhile, were placed on the dynamometer. The dynamometer was lifting up with a 42-degree angle against the table. The experiment contains eight trials in total for each surface. The dynamometer gave the read out of the friction forces during the experiment. The graphs below are two typical graphs of the transversal and normal forces during one of the COF tests.

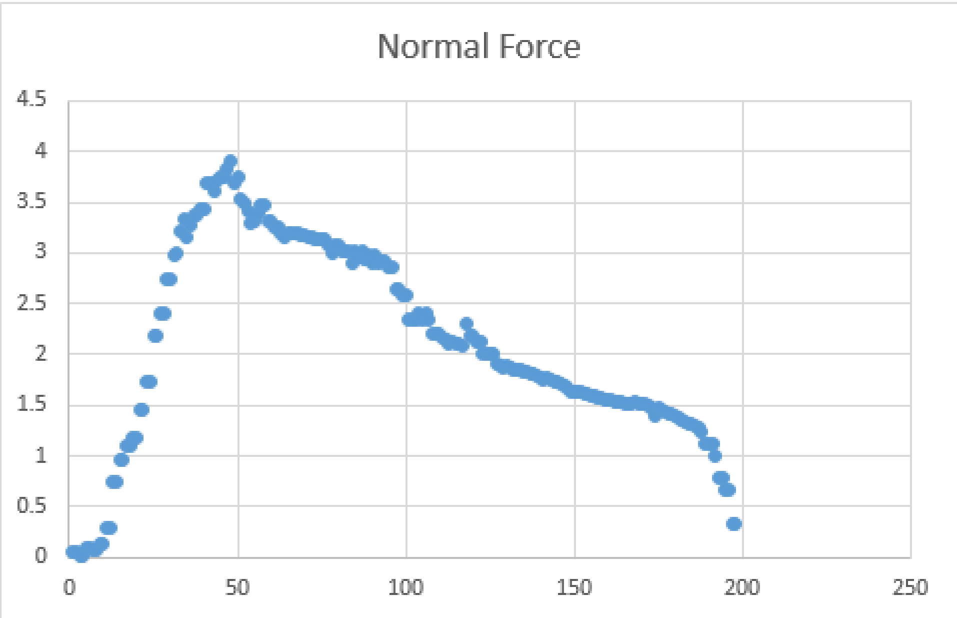

Figure 4: Normal Force Graph (Z-Direction)

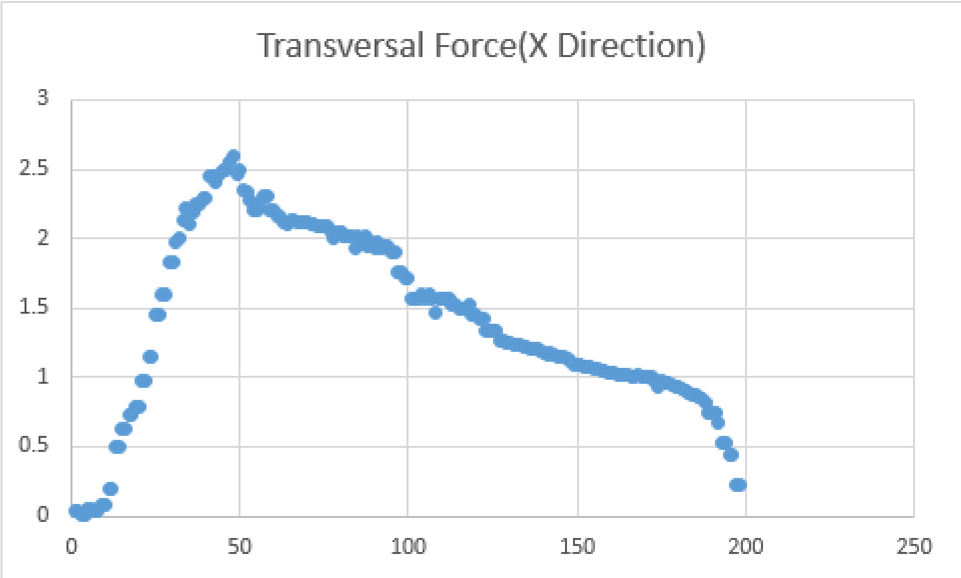

Figure 5: Transversal Force Graph (X-Direction)

These graphs are typical of our results in our tests. Both normal and transversal force increase at the beginning when the gold ball lands on the surface. Then they both decrease as the golf ball bounced off.

3.2.2 Coefficient of Friction

As the both normal and transversal forces were obtained, the COF could be calculated. The mean of Coefficient of friction of three testing surface were showed in the charts below.

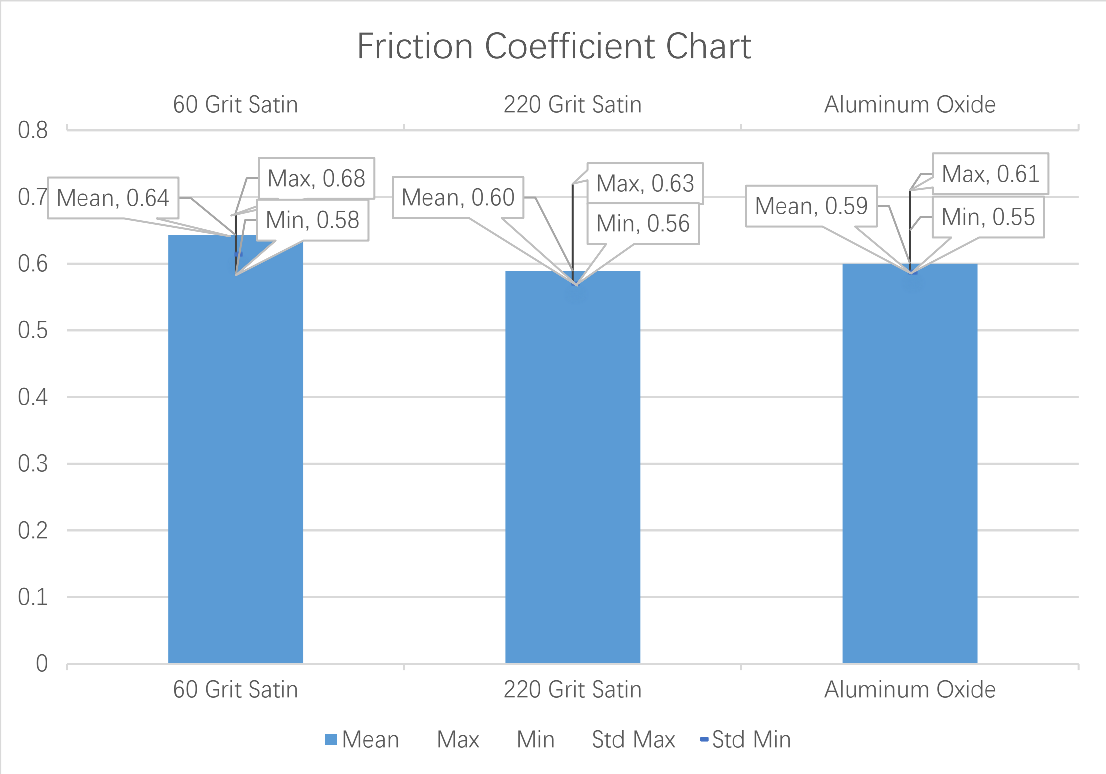

Figure 6: COF Results Chart

Since the golf ball was dropping by hand during the experiment, each time the height for drooping the ball might be varied. That could affect the force in both x and z-axis (Tangential Force and Normal Force). Also, the landing point on the testing surfaces could not guarantee to be same for each trial. Therefore, for future experiment, a better way for dropping the golf ball could result the data more accurate.

3.3 Spin Rate of Golf Ball

In order to find out the spin rate of golf ball after impact, a high speed camera was required to use and film the motion of the golf ball. However, by considering the weight and the value and the dynamometer, the experiment was eventually decided to be worked in Higgins Lab 031. It is difficult to carry the dynamometer over to Kaven Hall, which would cause possibilities to damage the device. In the future experiment, the high speed camera can help the group to get better knowledge of the surface roughness.

4. Discussion

4.1 Ball Release

In this experiment, the golf ball was released by hand, which could cause some problems to the final result. At the beginning, I was trying to find a better way to release the golf ball with minimal spin and high speed. However, I could not find the way to do that. In the future experiment, a good way to release the golf ball could help to improve the results.

4.2 Force Measurement

In order to fully understand the interaction between three surfaces, it is important to measure the forces simultaneously. The tangential friction forces directly related to the normal friction forces, therefore if the two forces are not measured simultaneously then the COF cannot be figured out.

4.3 Testing Surfaces

In this experiment, I selected three testing surfaces because they are related to the real golf club head. However, there is a broad number of materials that can be manufactured to golf club head. In the future experiment, other materials can also be tested in order to help the golf club makers to produce better golf clubs.

5. Conclusion

As the result I got from the experiment, the surface roughness does have a relationship with the COF. The surface roughness data were obtained by Olympus LEXT and analyzed by Mountains 7. The COF were resulted from both tangential and normal forces, which were obtained from the dynamometer. The greater COF represents the greater number of surface roughness.

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7. Acknowledgements

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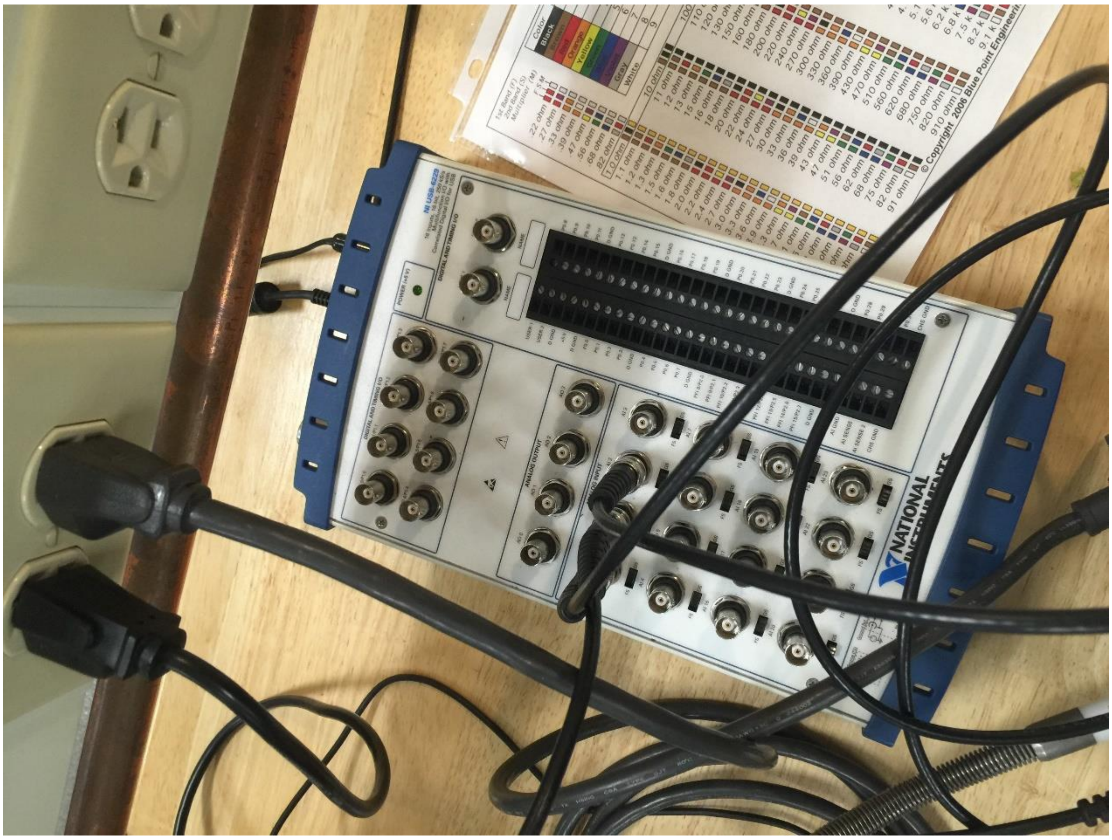
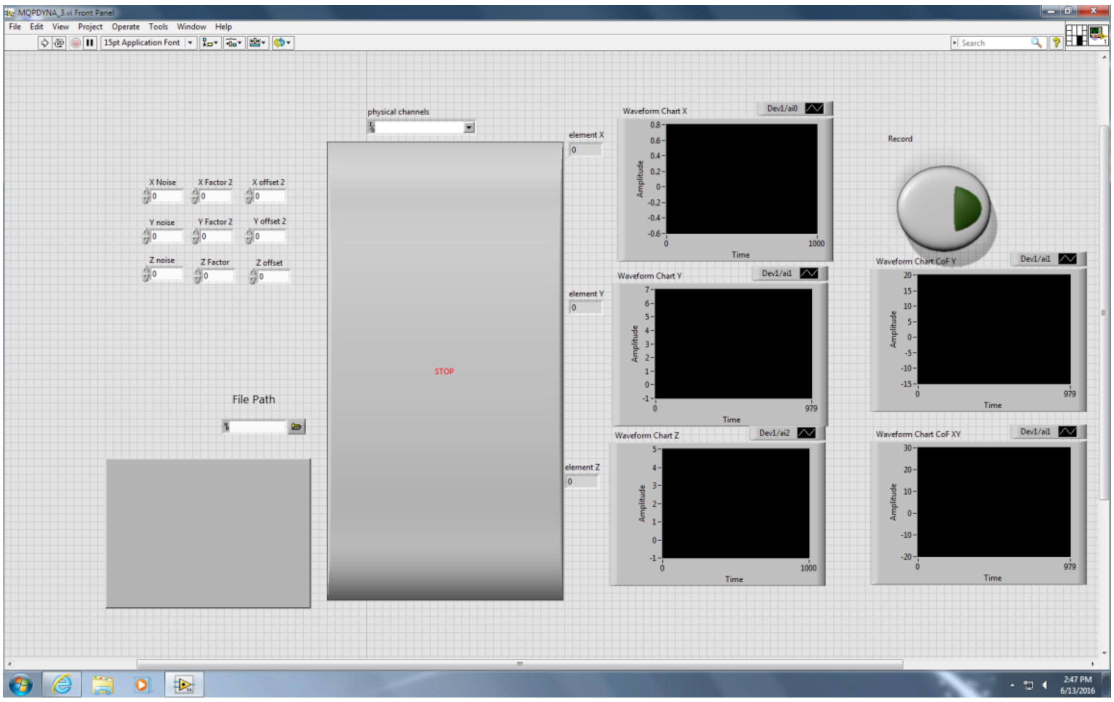
8. Appendix


NATIONAL INSTRUMENTS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X Noise
X Factor 2
X offset 2
Y noise
Y Factor 2
Y offset 2
Z noise
Z Factor
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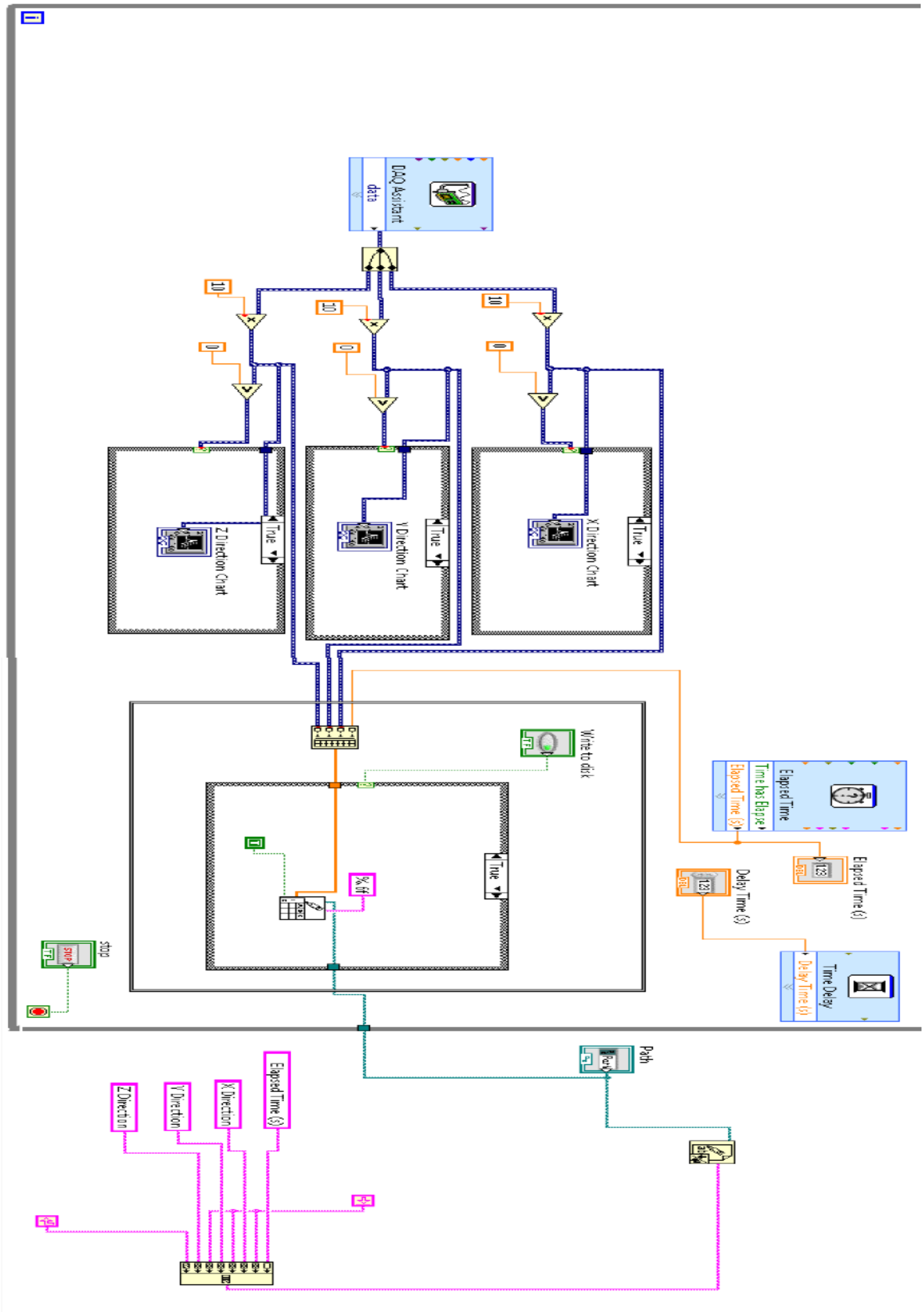

Figure 7: LabVIEW Works

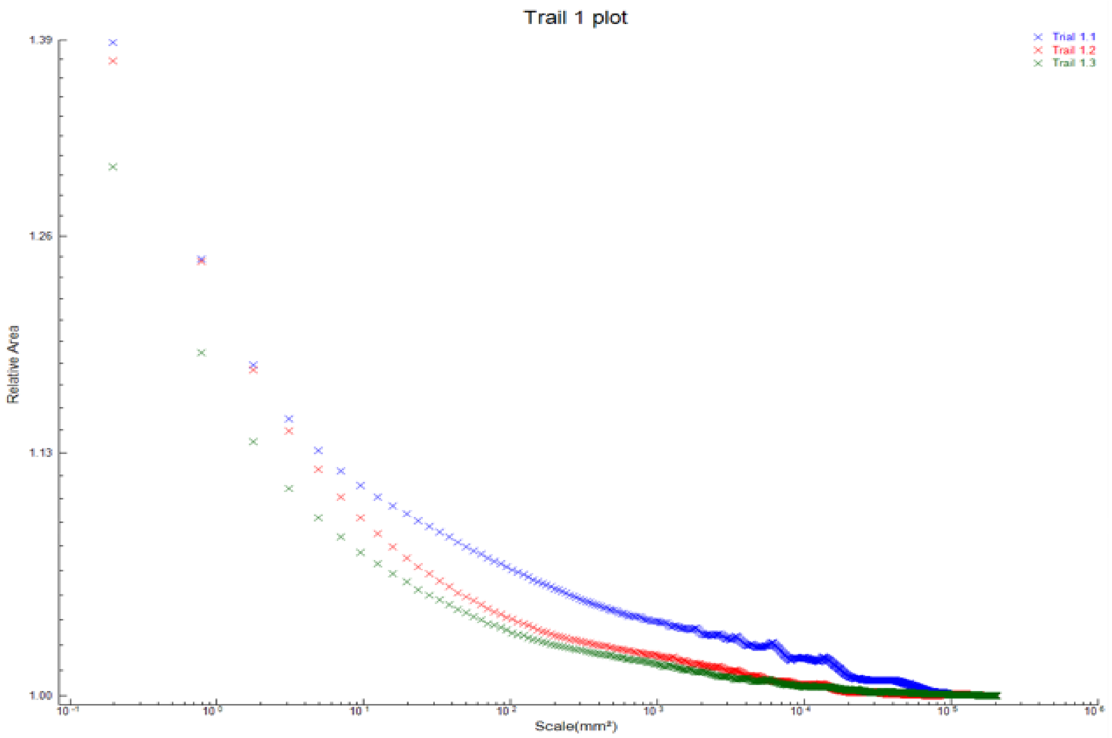

Figure 8: Sfrax File for 60 Grit Measurements at 20x

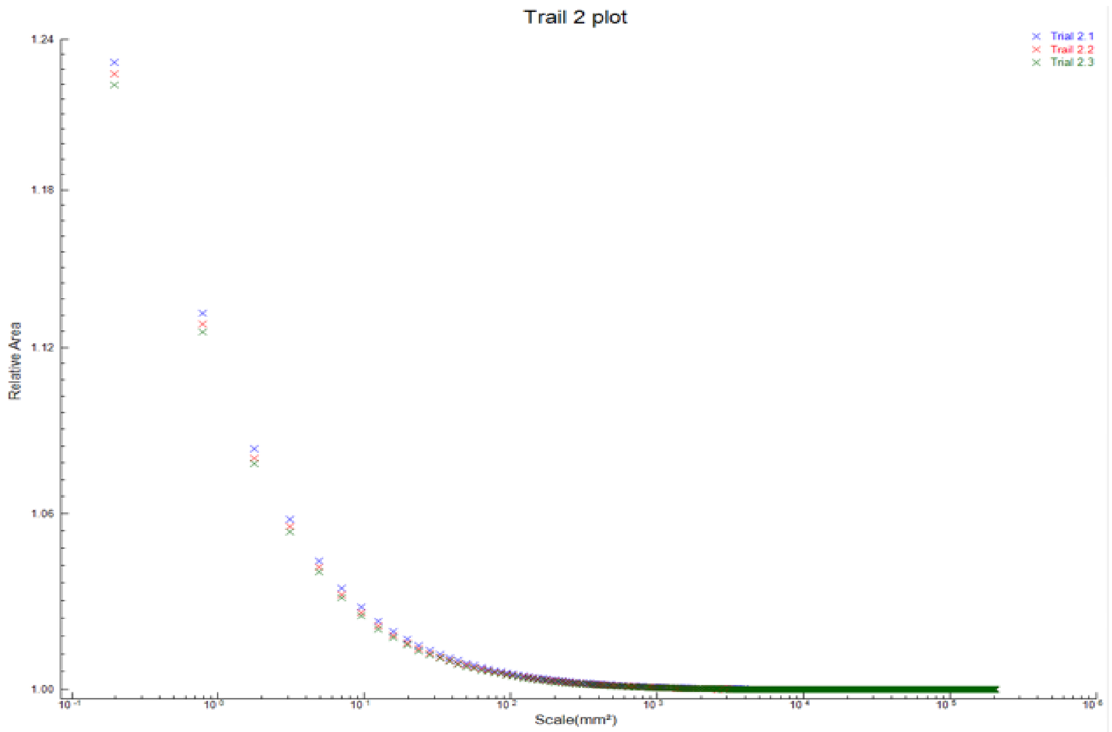

Figure 9: Sfrax File for 220 Grit Measurements at 20x

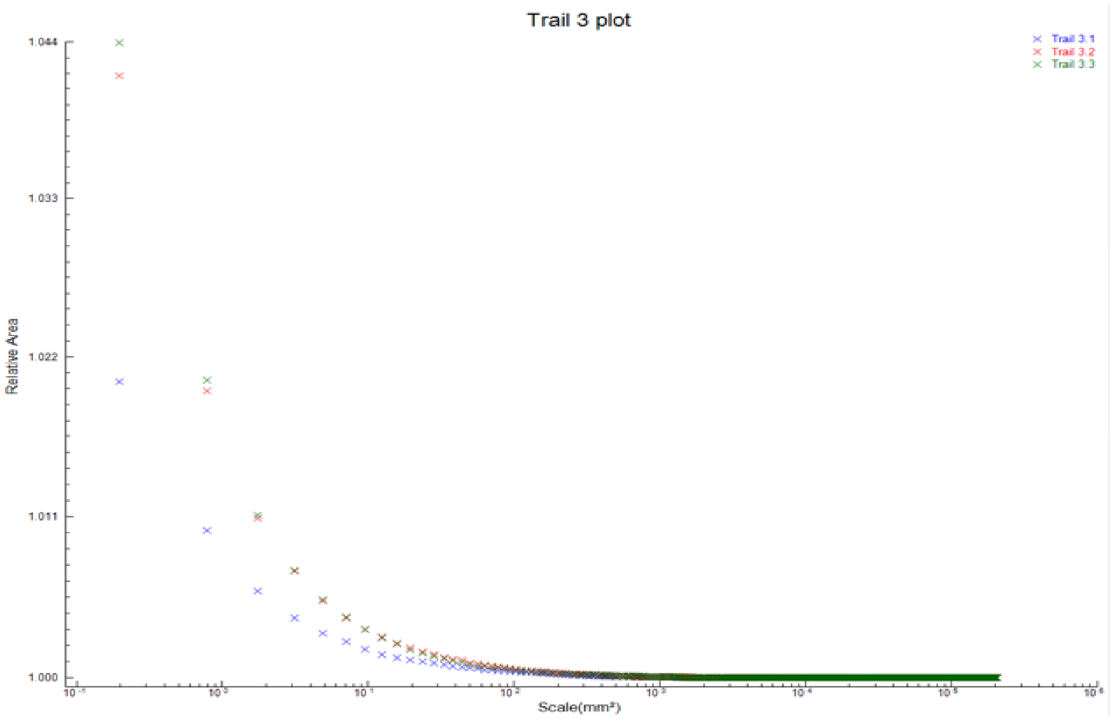

Figure 10: Sfrax File for Aluminum Oxide Measurements at 20x