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Paper

**Rz: A BETTER MEASUREMENT OF ABRASIVE WATERJET CUT
SURFACE FINISHES**

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ABSTRACT

The average roughness (Ra) measurements for machined surface finishes have become the standard default representation for abrasive waterjet machined surfaces. One of the assumptions behind the Ra surface finish is that the surface finish is uniform across the entire surface, and thus only a small inspection length is needed to represent the entire surface. With the presence of striations in abrasive waterjet cut surfaces, this underlying assumption is no longer valid. Since the peak to valley magnitudes in the striations also varies along the thickness of the workpiece, the use of Ra measurements as a qualification measurement is further eroded, especially when the location of the Ra measurement is not identified. This paper will be presenting a comparison between Ra and average peak to valley height (Rz) measurements along the thickness of an abrasive waterjet machined surface. By comparing the relative differences between Ra and Rz surfaces, it will be demonstrated that Rz measurements provide a more accurate representation of the surface finish of an abrasive waterjet machined surface.

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1 INTRODUCTION

Over the past 30 years of abrasive waterjet cutting development efforts, abrasive waterjet machining has moved from rough through cutting tasks to relatively high precision net shape finished parts. With the introduction of 5 axis cutting heads, CNC controlled taper compensation can be used to adjust the orientation of the waterjet nozzle vector so that the natural taper of the kerf surface within the cut can be tuned to align with the desired surface profile of the finished part [2, 3, 4]. By tilting the nozzle, an added benefit of increased cutting speed can be obtained for the same cut surface quality.

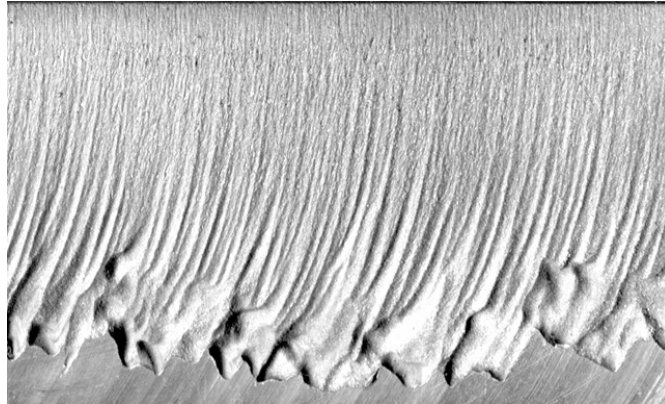


Figure 1. Non-through cut surface quality of an Abrasive Waterjet,

Figure 1 shows the worst case surface finish in a part where the abrasive waterjet did not cut all the way through the workpiece. The smoothest surface finish is at the top of the part and the worst is at the bottom of the workpiece. As the traverse rate of the cutting jet is slowed down, the abrasive waterjet will begin to cut completely through the workpiece, and the roughness of the surface will improve to look more and more like the surface finish that is observed at the very top of the cut surface.

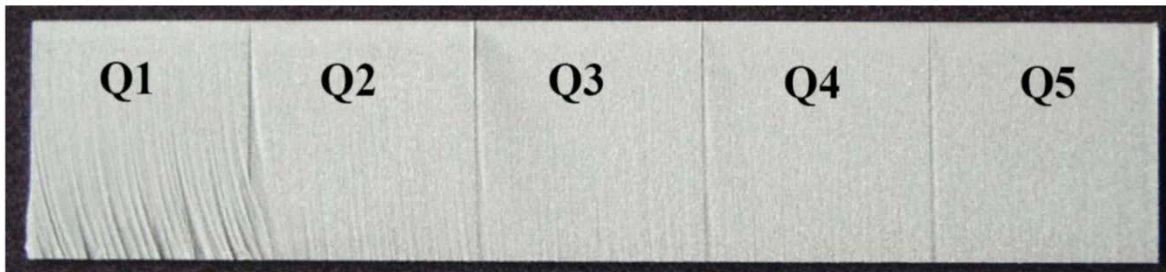


Figure 2. Abrasive waterjet cut qualities.

In 1992, Zeng [1] introduced the term called surface quality for selecting abrasive waterjet process parameters for different “qualities” of the abrasive waterjet cut surfaces. Where Quality 1 (Q1) is very rough with heavy striations, Quality 5 (Q5) is the smoothest striation free cut surface, and Quality 3 having some surface waviness and is often used for general purpose cutting operations. Figure 2 shows an illustration of this. Equation 1 is a simplification of Zeng’s model where k is a function of all of the abrasive waterjet process parameters, cutting speed, and material machinability. For a fixed set of parameters, the maximum cutting depth at a specific quality, h , is approximately an inverse function of the surface quality, Q

$$h \sim 1/Q \quad (1)$$

Since the introduction of the cutting process being a function of surface quality, Q , this has become one of the common methods to characterize the final surface finish of a part, and is used to determine the appropriate cutting process parameters for a desired surface quality.

Unfortunately, surface quality is a subjective term that is not associated to engineering units such as classical Ra or Rz measurements [5].

The purpose of this paper is to present a non-ambiguous and precise method to inspect abrasive waterjet machined surfaces so that the topological accuracies of the waterjet machining process surfaces can be measured using standard surface finish profilometers.

2 SURFACE FINISH MEASUREMENTS IN ALUMINUM

To evaluate the continually changing surface finishes in a workpiece, a 50 mm thick aluminum 6061-T6 was cut with a 0.38 mm orifice and 1.07 mm diameter mixing tube at 340 MPa with a cutting speed of 241 mm/min using 80 mesh abrasives flowing at 3.1 kg/min. Surface finish measurements were obtained using the Pocket Surf® PS1 surface finish profilometer manufactured by Mahr Federal Inc. Surface finish measurements were obtained over an inspection length of 17.5 mm to ensure proper surface finish measurements across the striations. Figure 3 shows a photograph of this test sample, and surface finish measurements are shown in Figure 4.

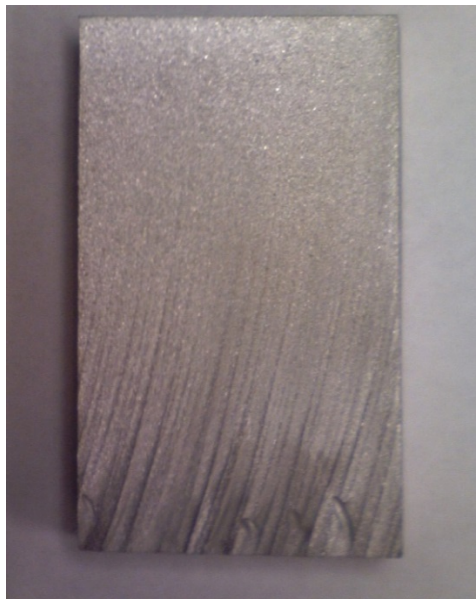


Figure 3. Surface finish test sample

Figures 7 through 22 shows the measured surface finish measurements for each inspection location. The surface finishes near the top surface of the workpiece shows more of a classical

surface roughness measurement for a striation free cut surface, with an occasional pit that causes large R_t deviations. Signs of striations start to become apparent at a depth of 7.6 mm (Figure 10), and the striations becomes obvious at 15.2 mm (Figure 13). At 25.4 mm (Figure 17), the local surface roughness measurements are becoming indistinguishable from the high peak to valley measurements of the striations. Visually with the human eye, the striations appear to be very small, but from measurements, they appear to be very large. At 33 mm (Figure 20), the measurements are primarily the striations since the relative magnitude of the local surface roughness is negligible when compared to the peak to valley amplitudes. In Figure 22 (38.1 mm depth), the flats that are observed at the bottom of some of the valleys are due to the stylus tip of the profilometer reaching its maximum extension and couldn't reach further into the valley. Surface finish measurements 38 mm from the top edge of the test sample were not obtainable with the Pocket Surf PS1 since it exceeded the maximum inspection range of this instrument.

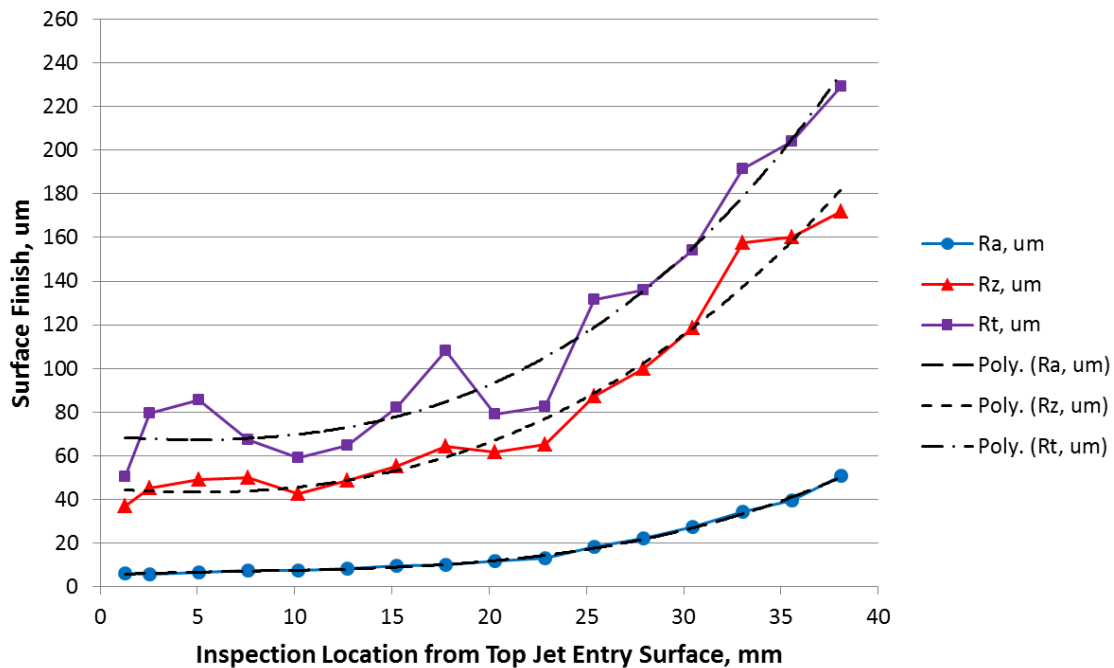


Figure 4. Surface finish measurements in 50 mm thick aluminum.

In Figure 4, it can be seen that the average surface finish, R_a , gradually and smoothly increases along the depth of the workpiece. The smoothest finish occurring at 1.27 mm from the top of the workpiece (jet entry surface), and is worse at the depth 38 mm. The average peak to valley measurement, R_z , also increases along the depth, along with the maximum peak to valley measurement (R_t). Near the top portion of the cut surface there are no observable striations, but as the depth increases the surface waviness becomes worse. This is indicated by the rapidly increasing magnitudes in the R_z measurements. Because of that, the net R_a measurements also increased. The R_t measurements has a much greater variation because it is the maximum peak to valley measurement and is very sensitive to part cleanliness and pits and scratches on the surface of the part. When fitting each of the data sets with a third order polynomial, there is an almost perfect fit with the R_a measurements, and a very good fit with the R_z measurements. Though the

deviations between the R_t measurements and the R_t trend line are much higher, a third order polynomial is a good fit for the data set as a whole.

In conventionally machined surfaces, the R_z measurements typically range between 5 to 7 times the R_a measurements. Figure 5 shows the ratio of the R_z to R_a measurements for this waterjet machined surface. It can be seen in this Figure that as the striations become more pronounced, the R_z to R_a ratio drops well below the 5 to 7 rule. The surface finishes along the slopes of the striations have an additive effect on the overall average roughness measurements. When evaluating the data set as a whole, the R_z/R_a ratio linearly decreases as the cutting depth increases (dashed line in Figure 4). Henning [6] observed that four times the standard deviation of the raw surface finish data provides a similar result that is obtained with R_z measurements with the added advantage of being less sensitive to extreme outlier data. But since profilometers do not provide standard deviation results, R_z measurements are easier to obtain.

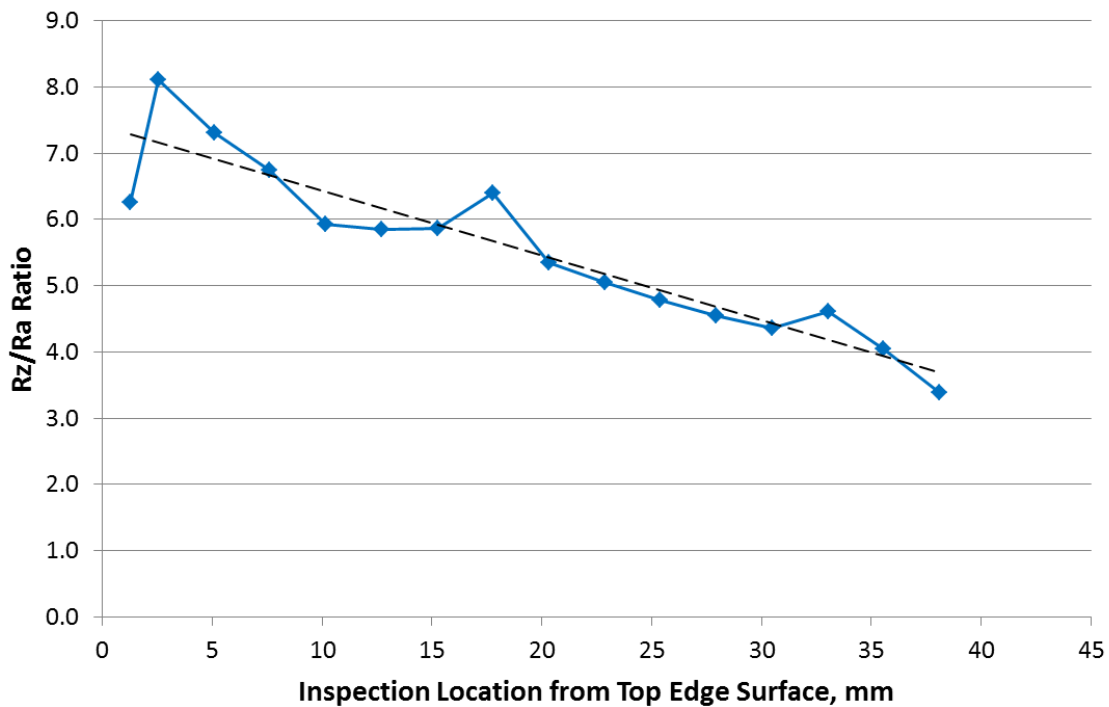


Figure 5. R_z to R_a ratio along the depth of the waterjet cut surface.

3 ABRASIVE MESH SIZE EFFECTS ON SURFACE FINISH

Surface finish measurements are also greatly affected by the type and size of the abrasive particles being used to cut the workpiece. Figure 6 shows a set of striation free surface finish measurements at the midpoint in 3 mm thick aluminum for various abrasive mesh sizes. It can be seen that as the average abrasive particle size decreases, both the R_a and R_z measurements also decrease. From a surface quality point of view, all 5 different mesh size samples had the same striation free surface equivalent to surface Quality 5, and yet the surface finishes are greatly different for the different abrasive mesh sizes.

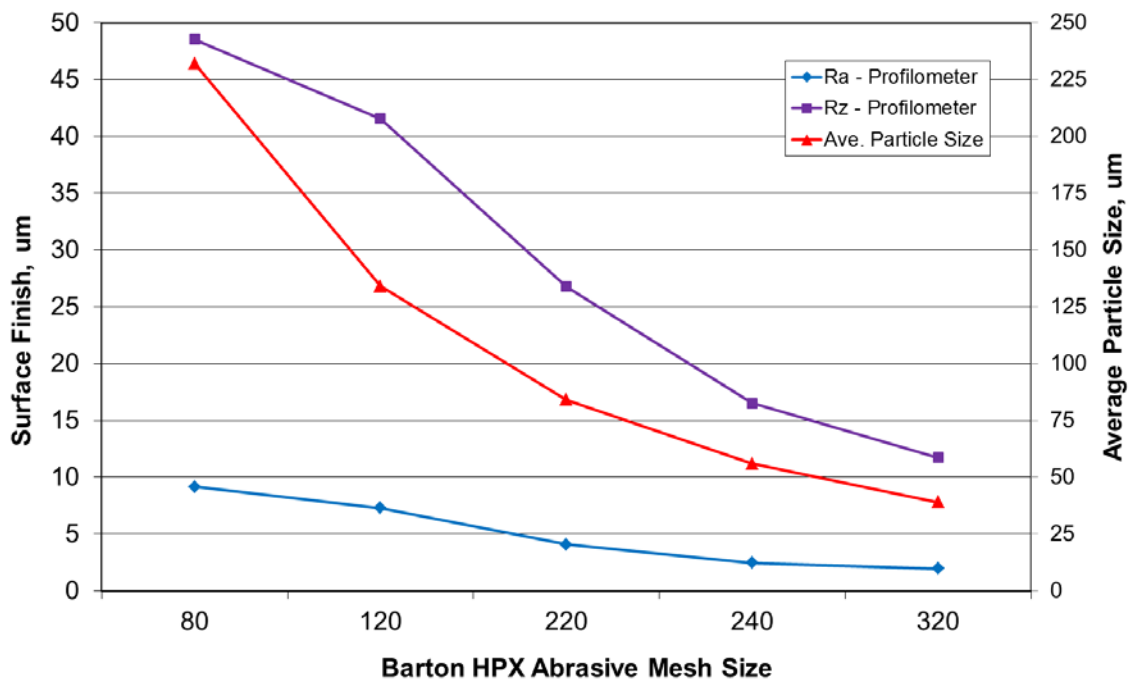


Figure 6. Surface finish measurements at the midpoint in 3 mm thick aluminum.

4 SURFACE FINISH AS A MEASURE OF SURFACE QUALITY

Using Ra as a measure of surface quality can be very misleading especially when the location of the surface finish is not specified. A poor quality part with heavy striations can yield a very good surface finish if the measurement was taken near the top of the workpiece. Two identical parts with a small amount of striations near the exit surface can yield vastly different results if they are inspected by different people because one person may be under pressure to pass the parts by inspecting the top edge of the workpiece whereas a different person using the worst case criteria and inspects the bottom edge of the part. In this case, the part passing inspection depends on the inspector and the location of the surface finish location.

Another example would be a part that has an average surface finish requirement of 5 um. This may automatically be assumed to be a Quality 5 surface finish. Figure 6 shows that 220 mesh or finer abrasives would be required since 80 mesh abrasives could not produce this type of a finish. But if a 320 mesh abrasive was utilized, and visually large striations are present, the Ra finish may be well within specifications, but the visible striations may put the part at quality 1 or 2 which would be visually unacceptable.

The previous discussion illustrates problems with using a Quality or the Ra surface finish specification. An improved method to specify the final surface roughness/Quality that is not subjective to abrasive type, size, or human eye interpretations is to use the Rz surface finish at the bottom of the workpiece method. The Rz surface finish method provides a more accurate representation of the surface roughness and surface waviness in a single measurement than using

the Ra measurement. Since a majority of abrasive waterjet machined surfaces have some level of striations present, a measure of the surface waviness must be included in the quantification of the overall surface roughness. When using the Rz method, the surface roughness interpretation becomes independent of the abrasive type or size, and when the Rz measurements are obtained from the bottom edge of the workpiece, it captures the waviness of the striations in the cut surface. The inspection length should be at least 10X longer than the mixing tube diameter to properly capture the peak to valley measurements from striations from the cutting process.

One of the key points with the Rz inspection method is the physical location of the Rz measurement. This should be at the bottom 10% of the part's thickness or 2 mm, whichever is less. This captures the worst case surface finish of the machined part. In parts where it is difficult to obtain a measurement either because the part is very thin or the peak to valley striations exceed the limits of the profilometer, a subscript can be added to the Rz nomenclature to identify the distance from the bottom edge of the part where the measurement was taken. For example, if the measurement was taken 3 mm from the bottom edge, the measured surface roughness can be identified as Rz₃.

5 CONCLUSIONS

When manufacturing parts, unless a part drawing specifically the details of the cutting process, the production operation should be free to choose whatever parameters they prefer to use as long as the surface roughness of the finished part meets required specifications. When it comes to determining the final surface quality of a workpiece, hard measurements are the preferred method to inspect a part instead of using subjective methods. Since Ra measurements are highly dependent on the abrasive type and size, along with the location of the measurement, Ra measurements is a poor measurement to quantify the surface quality of abrasive waterjet cut surfaces.

Surface finish measurements using the Rz method provides a uniform, repeatable, and traceable method to inspect part surfaces that is independent of the abrasive waterjet manufacturing process used and is not subjective to human eye interpretations. Since all commercially available electronic surface finish profilometers also provide Rz measurement results along with Ra measurements, using the Rz inspection method can be immediately implemented in all production facilities without having to invest in new hardware.

Also, the use of the Rz method enables direct cutting performance comparisons between different manufacturing companies and research organizations because the quality of the cut surface is the final measure of the finished part.

6 ACKNOWLEDGEMENTS

The authors wish to thank Andrew Turpin, Ernst Schubert, and Dr. Peter Liu of OMAX Corporation for their work in developing and collecting the fine abrasive surface finish test samples.

7 REFERENCES

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8 APPENDIX

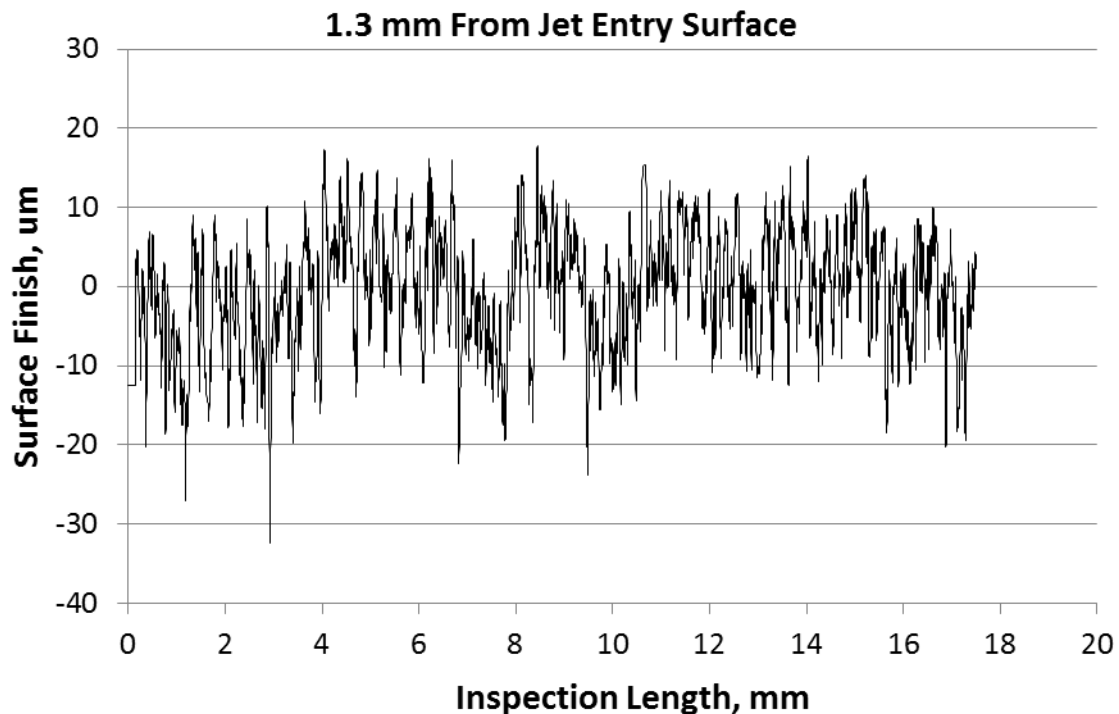


Figure 7. Surface finish measurements 1.3 mm from jet entry surface.

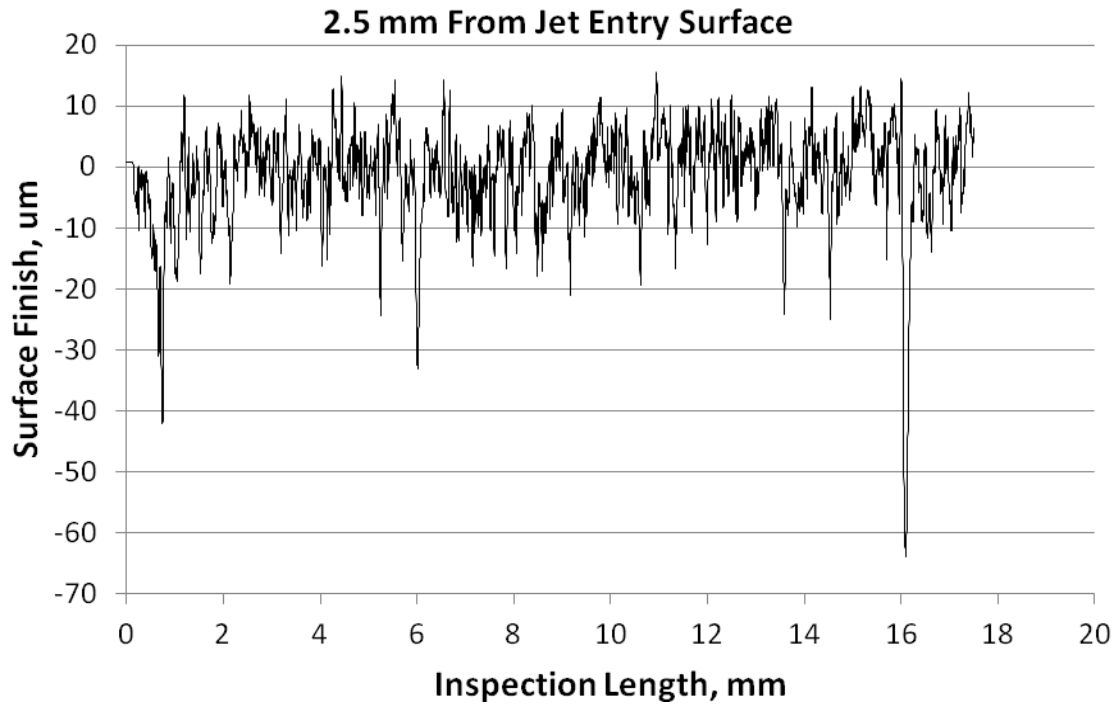


Figure 8. Surface finish measurements 2.5 mm from jet entry surface.

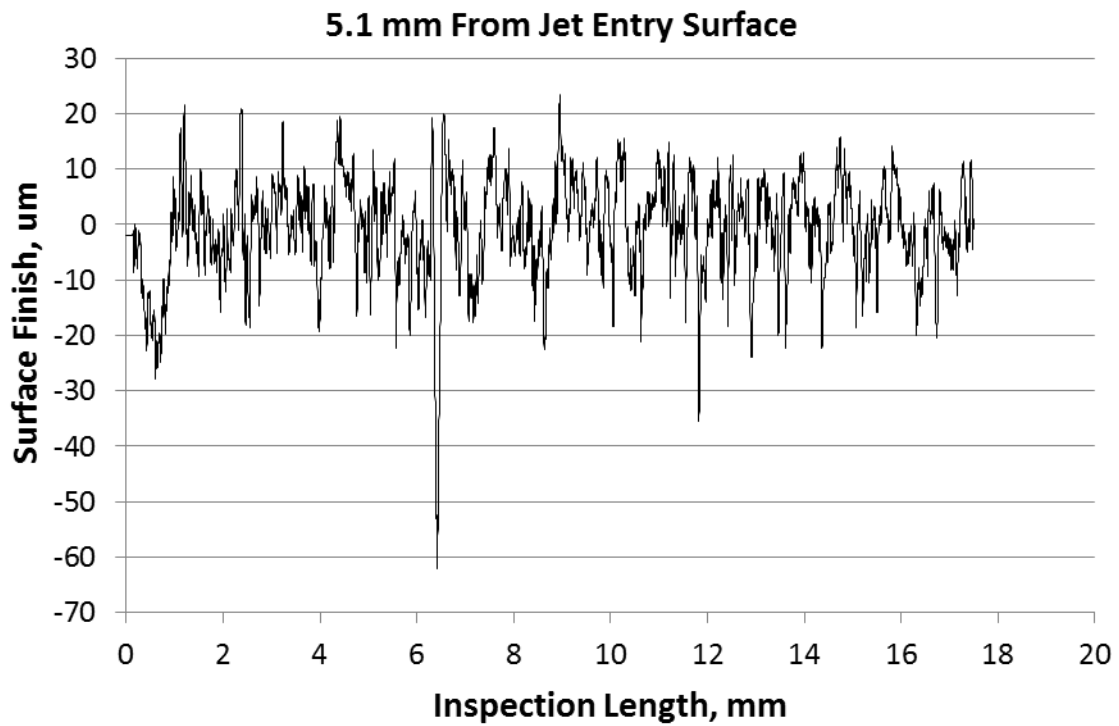


Figure 9. Surface finish measurements 5.1 mm from jet entry surface.

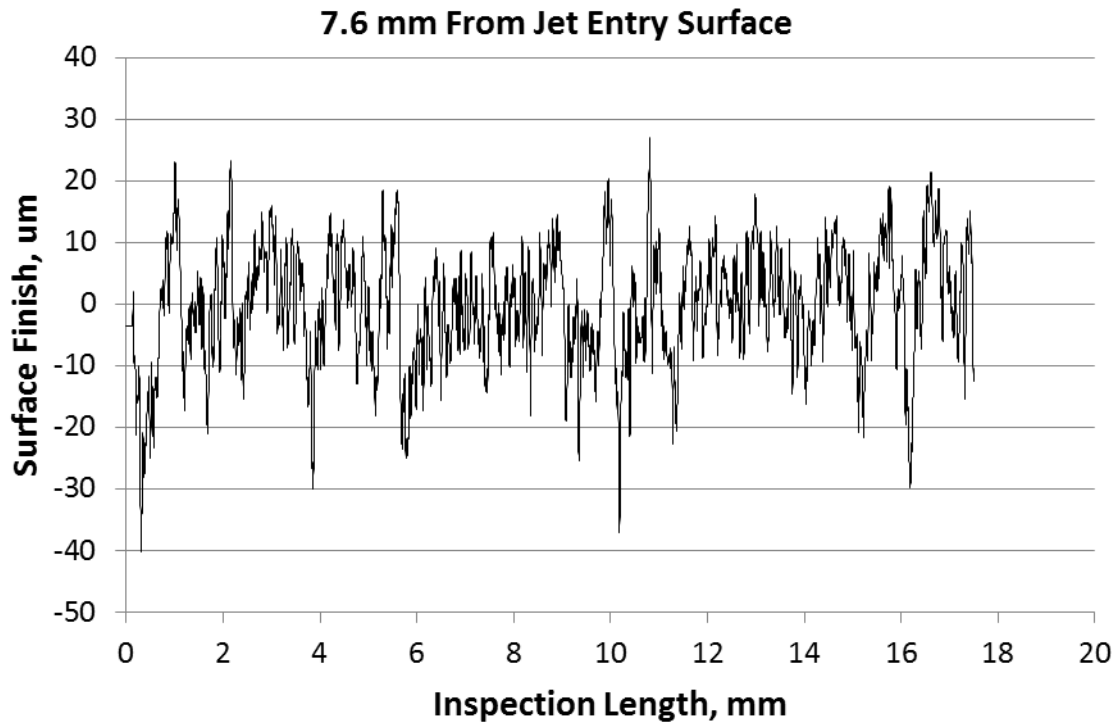


Figure 10. Surface finish measurements 7.6 mm from jet entry surface.

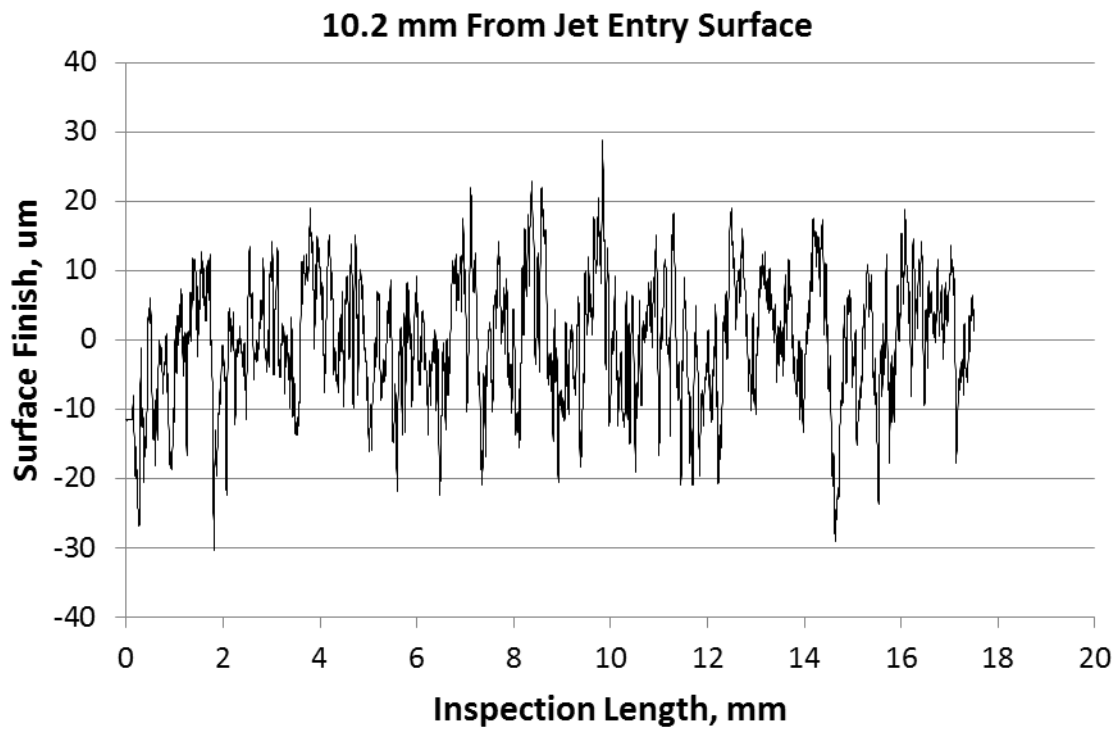


Figure 11. Surface finish measurements 10.2 mm from jet entry surface.

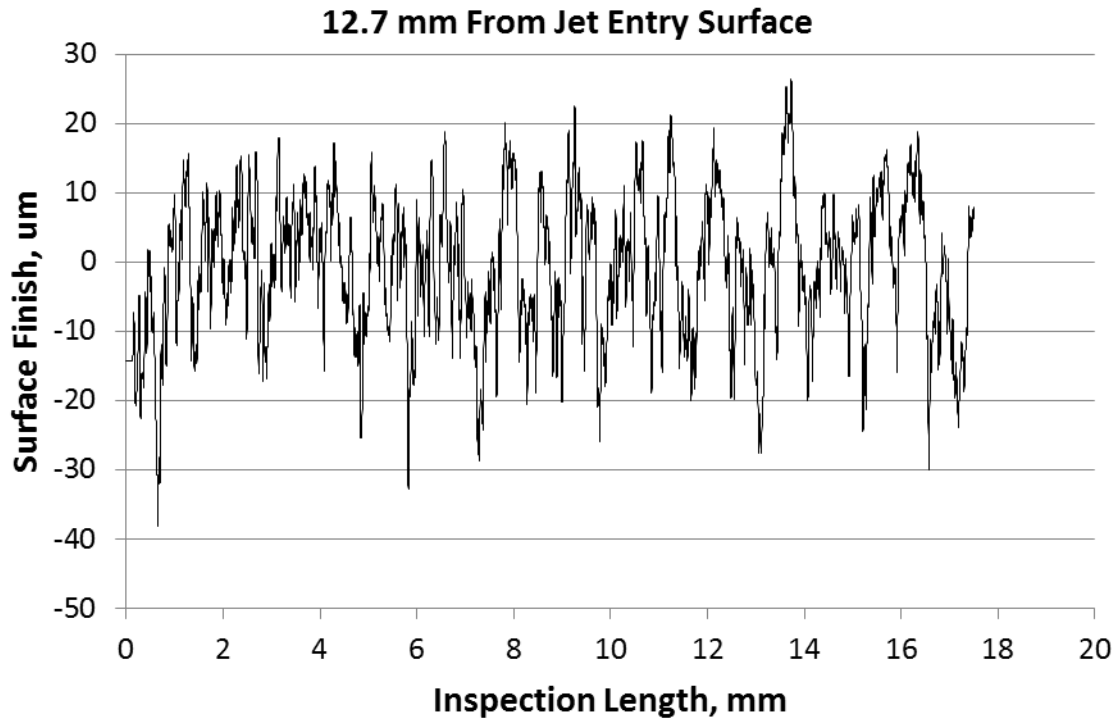


Figure 12. Surface finish measurements 12.7 mm from jet entry surface.

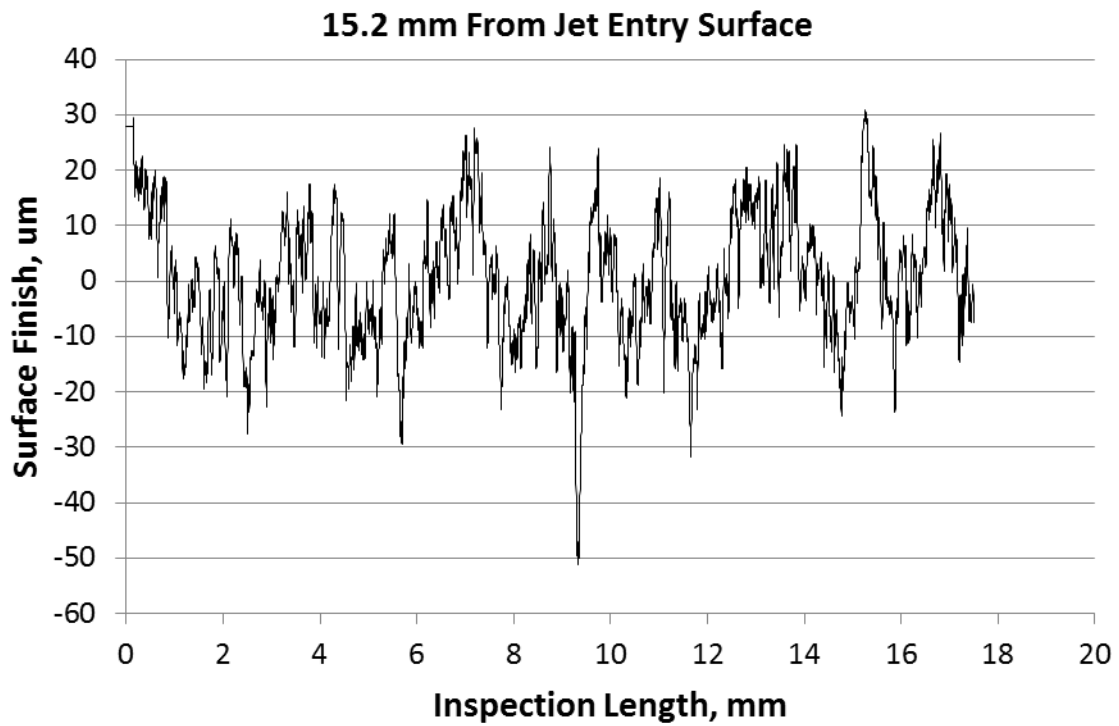


Figure 13. Surface finish measurements 15.2 mm from jet entry surface.

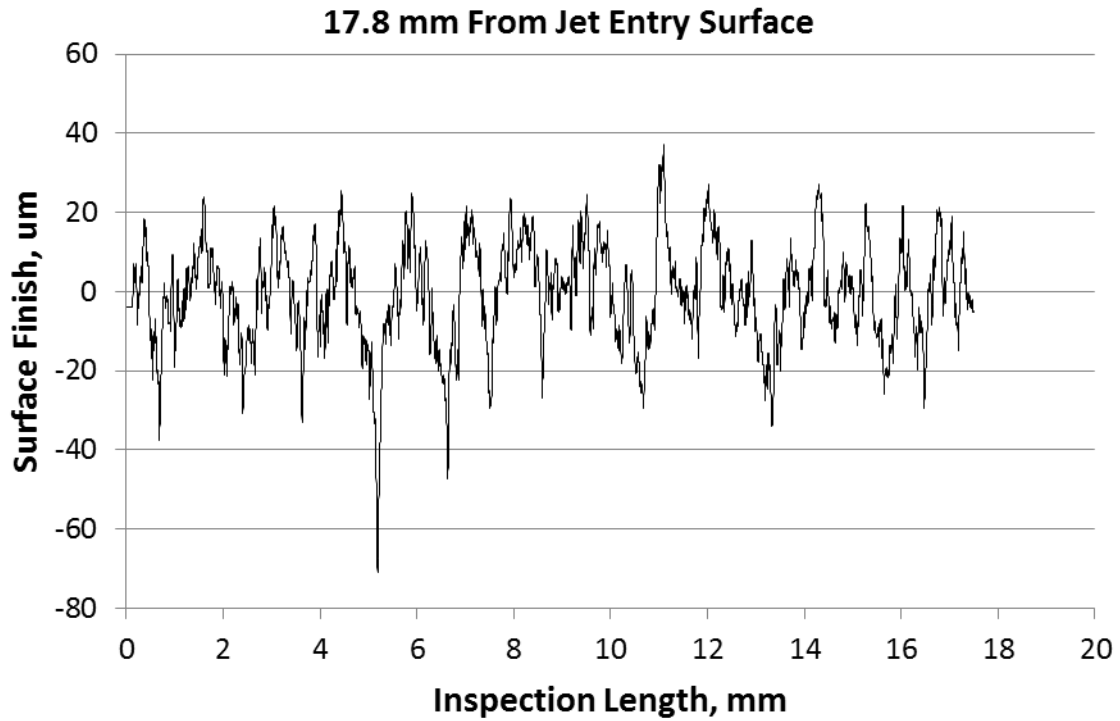


Figure 14. Surface finish measurements 17.8 mm from jet entry surface.

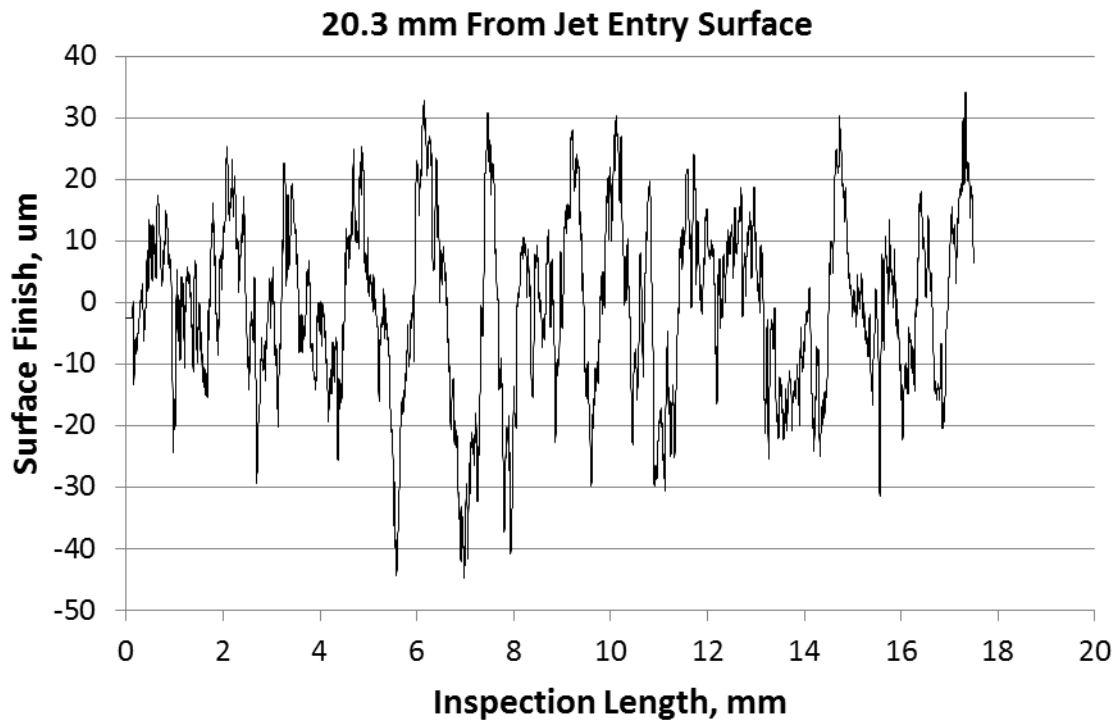


Figure 15. Surface finish measurements 20.3 mm from jet entry surface.

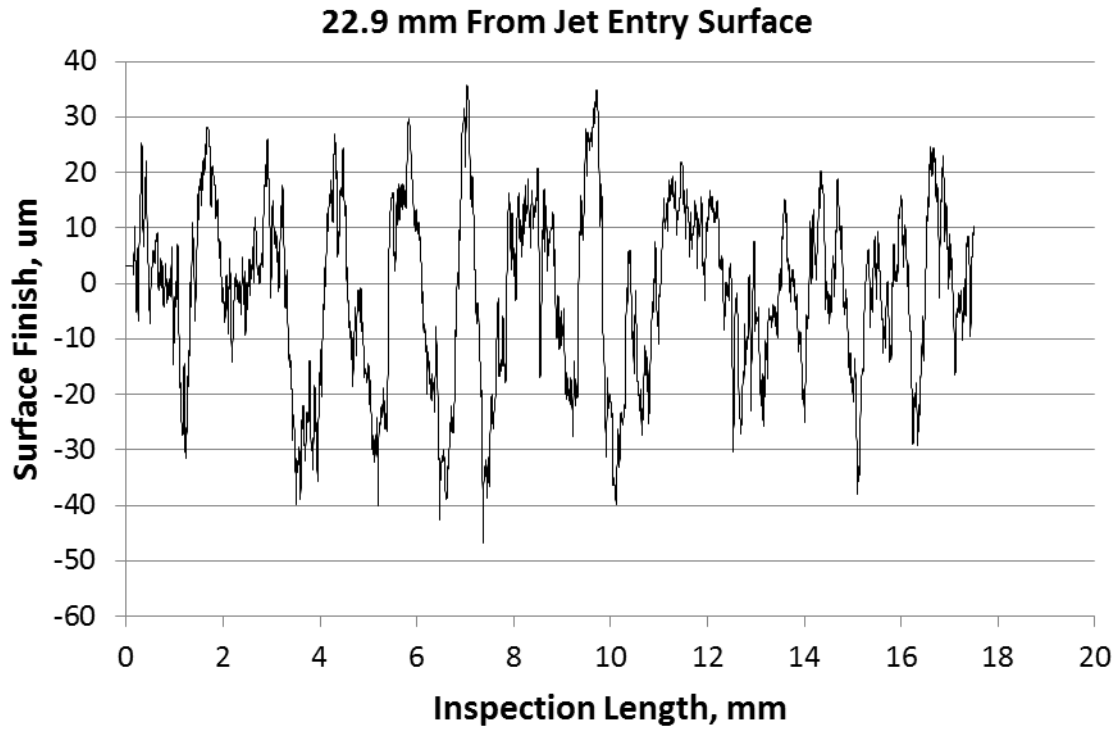


Figure 16. Surface finish measurements 22.9 mm from jet entry surface.

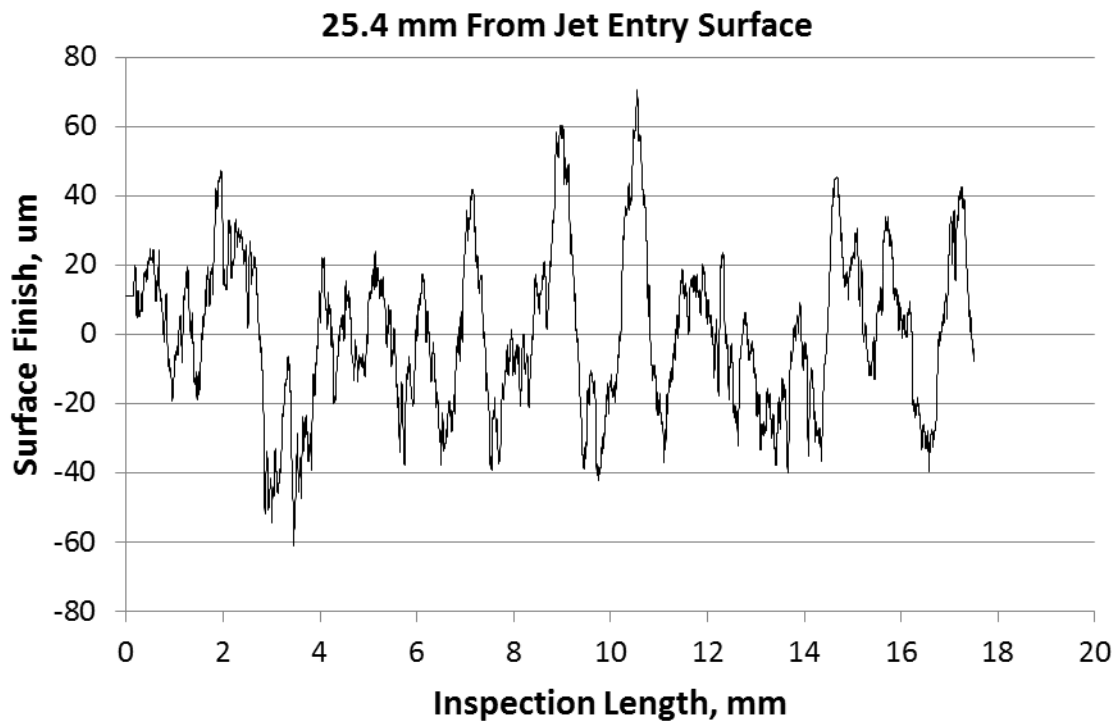


Figure 17. Surface finish measurements 25.4 mm from jet entry surface.

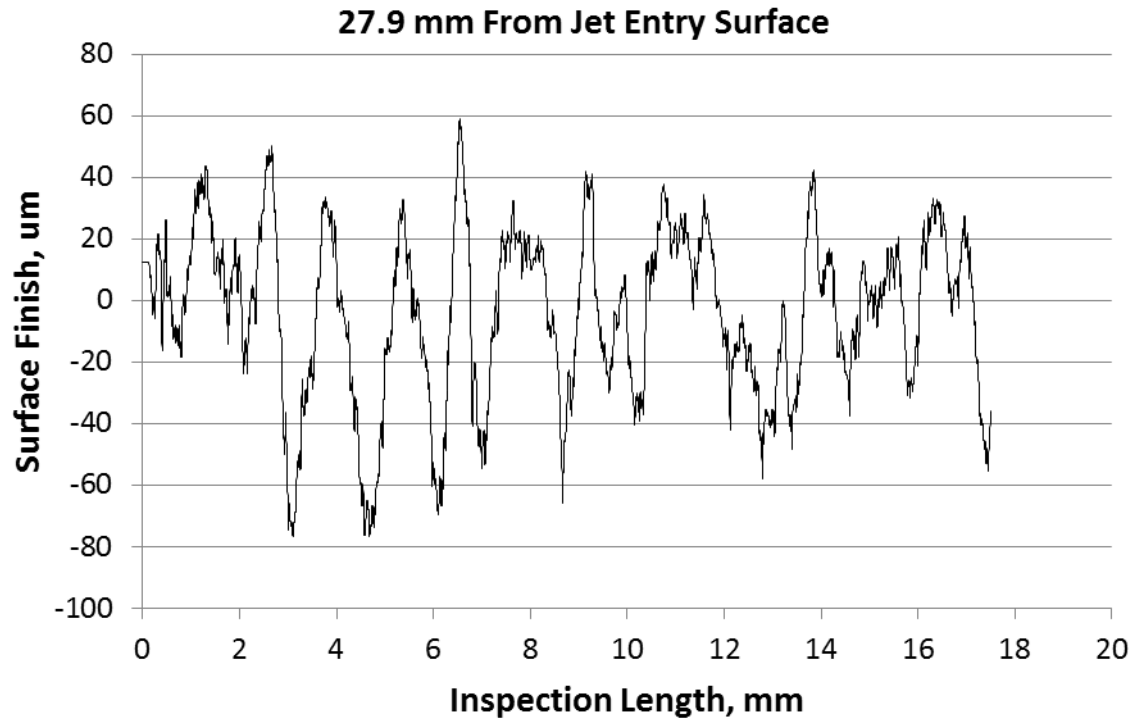


Figure 18. Surface finish measurements 27.9 mm from jet entry surface.

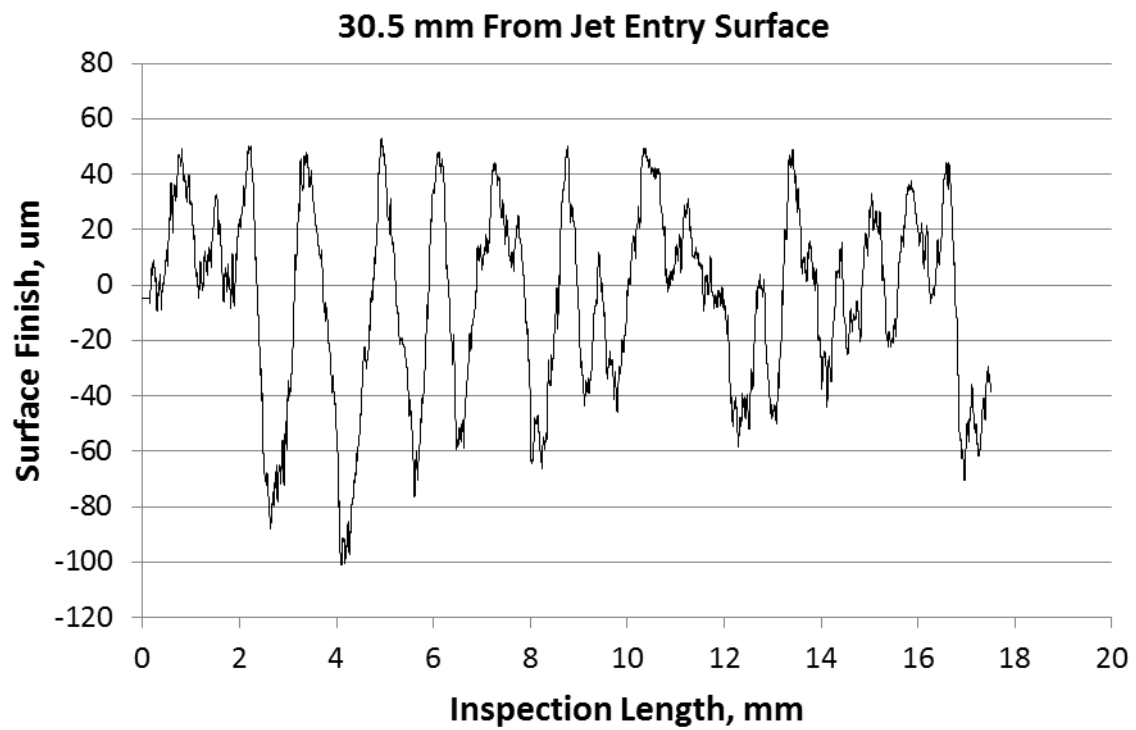


Figure 19. Surface finish measurements 30.5 mm from jet entry surface.

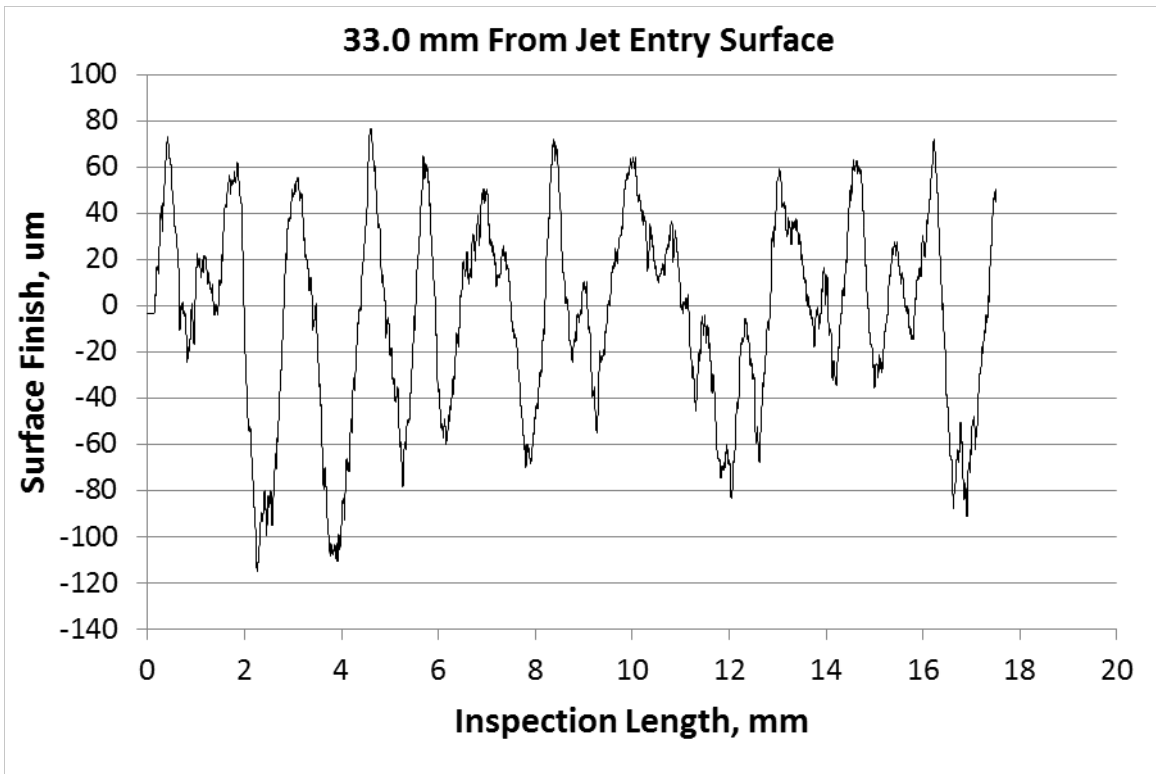


Figure 20. Surface finish measurements 33.0 mm from jet entry surface.

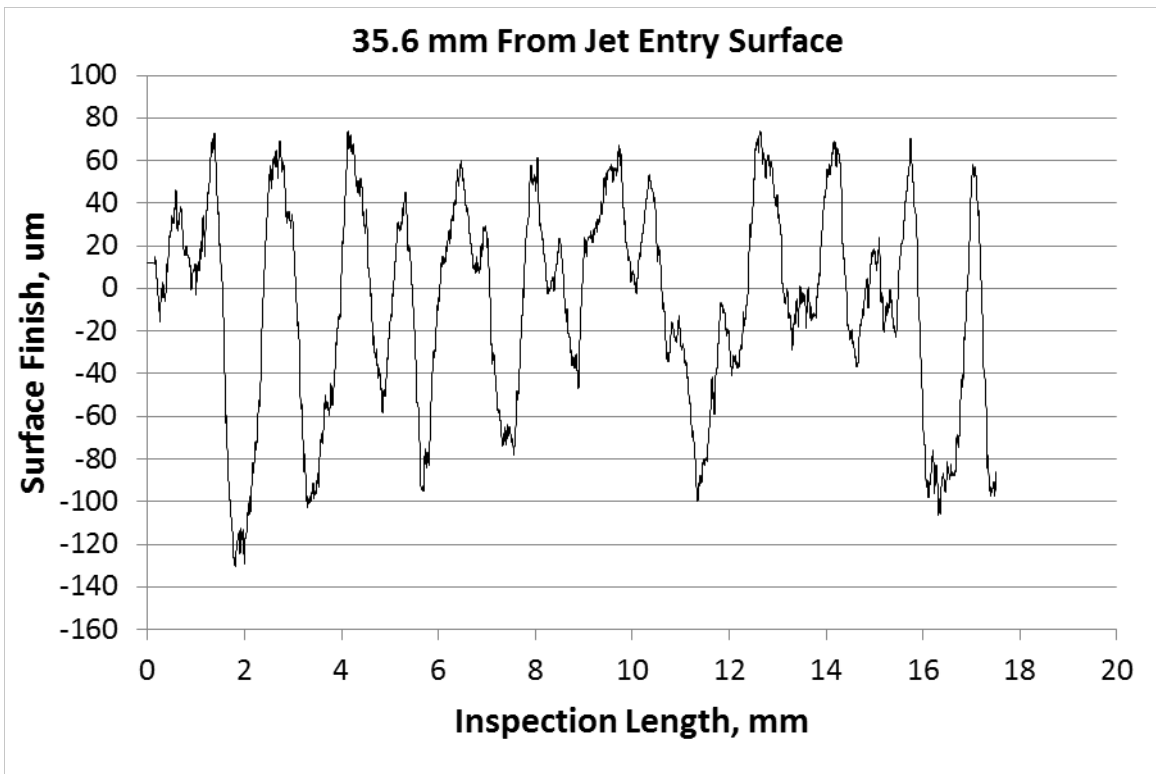


Figure 21. Surface finish measurements 35.6 mm from jet entry surface.

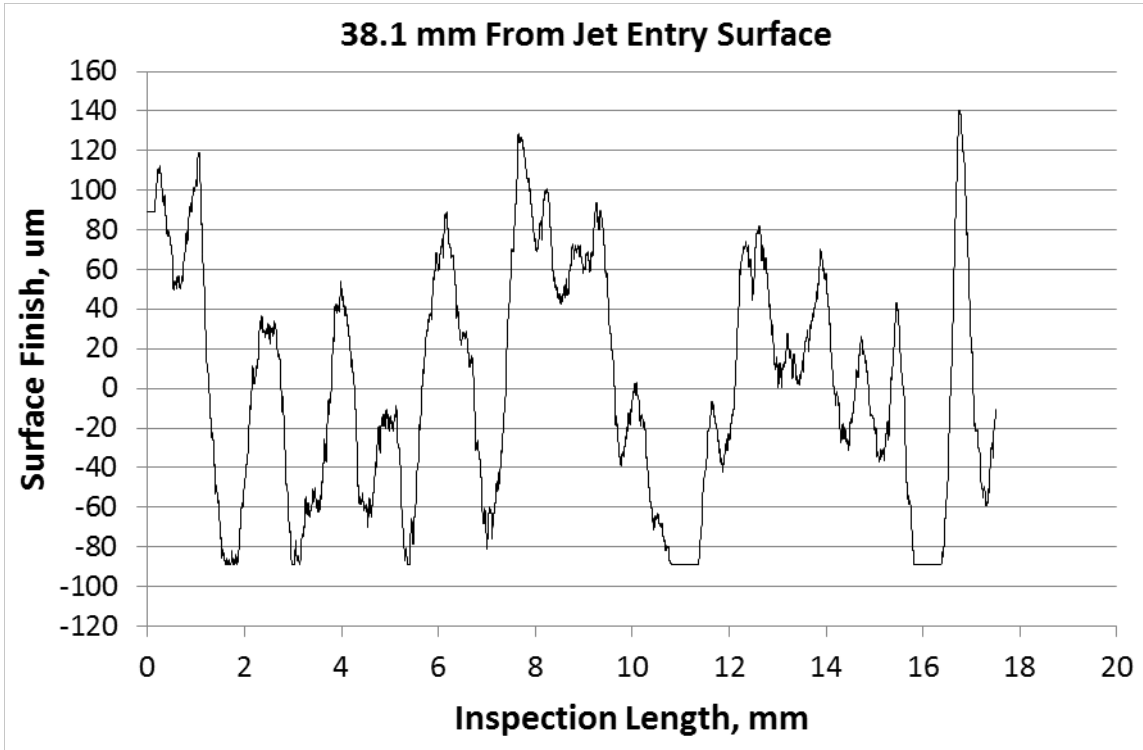


Figure 22. Surface finish measurements 38.1 mm from jet entry surface.