

A Comparative Study of the Mechanical Properties and Surface Characteristics of CR4 Mild Steel and 304 Stainless Steel after Milling and Abrasive Water Jet Cutting

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Introduction

This project investigated how two manufacturing methods, milling and abrasive water jet (AWJ) cutting influenced the mechanical behaviour and surface quality of two materials commonly used in the Swansea University Faculty of Science and Engineering, CR4 mild steel and 304 stainless steel. These materials are frequently used in student and research projects, making them ideal candidates for this practical study. By reviewing the dimensional accuracy, surface roughness and tensile properties of tensile samples manufactured to ISO 6892-1 standard, the project identifies which machining method, and its parameters, suits each material. The findings help inform machining strategies used in the university workshop.

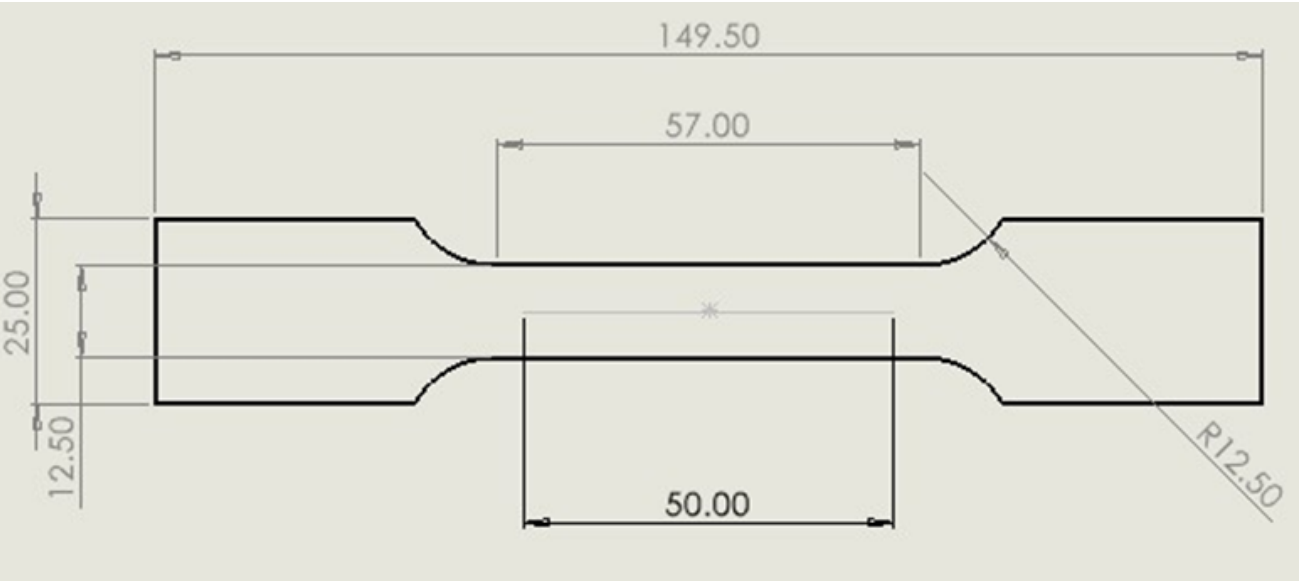


Figure 1— Tensile sample dimensions for ISO 6892-1

Project Aims and Objectives

Aim: To compare the effects of milling and AWJC on the mechanical properties and surface characteristics of CR4 mild steel and 304 stainless steel, from the data found, provide guidance on the most suitable machining methods for different applications.

Objectives:

- Manufacturing of standardised tensile test specimens from stock of both materials using both machining methods.
- Apply varying process parameters (tool diameter, spindle speed, feed rate for milling, cut quality for AWJ cutter) to asses their influence.

Parameter	Spindle	Feed Rate	Cutter Diam-
One	1200	300	12
Two	1200	90	12
Three	800	300	12
Four	800	90	12
Five	1600	360	6
Six	1600	150	6
Seven	1200	360	6
Eight	1200	150	6

Table 1— Cutting parameters for milled mild steel samples

Cut Quality	Cutting Speed (mm/min)	Abrasive used (kg)	Time to cut one sample (seconds)
One	616.93	0.158	54
Three	333.91	0.268	88
Five	184.47	0.462	134

Table 2— Cutting parameters for AWJ cutter mild steel samples

- Conduct uniaxial tensile testing to ISO 6892-1 to determine tensile strength, yield strength, Young's modulus and elongation.
- Measure and compare surface roughness Ra values using a stylus profilometer.
- Analyse and compare the mechanical and surface roughness data across both machining methods and materials.
- Provide recommendations for machining strategy based on performance, efficiency and suitability.

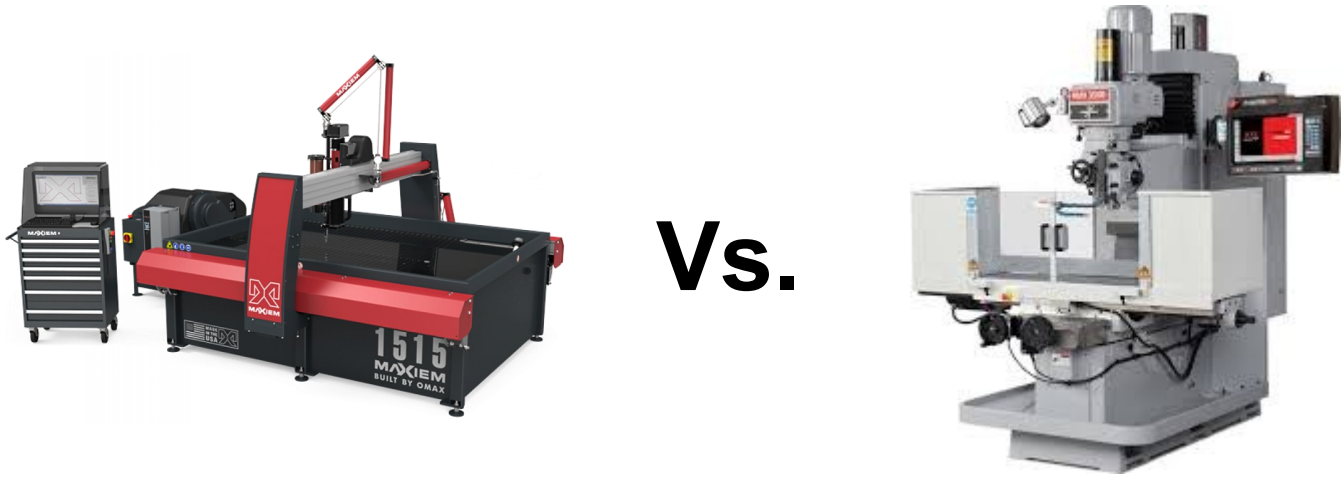


Figure 2— AWJC Vs. Milling

Methodology

This looked at following a structured workflow from the obtaining of materials to data analysis. Illustrated is the key stages involved in machining, testing and evaluation of the data obtained. Each of these steps was carefully planned out to ensure the project followed standardisation and a fair test for a meaningful between milling and AWJC.

1. Material Preparation

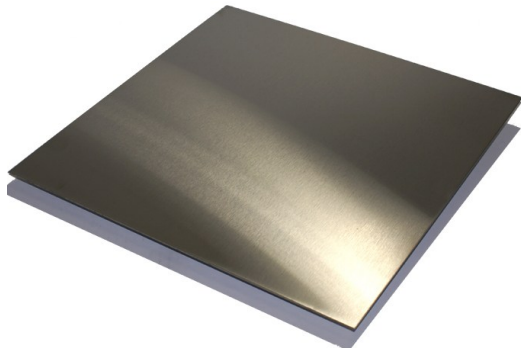


Figure 3

Figure 3 shows the 500mm x 500mm 304 stainless steel sheet bought from a reputable supplier.

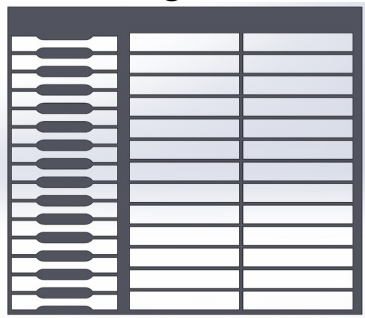


Figure 4

Figure 4 is a visualisation from SOLIDWORKS of how the samples were prepared from the sheet metal by AWJ cutting and guillotine.

2. Machining Process

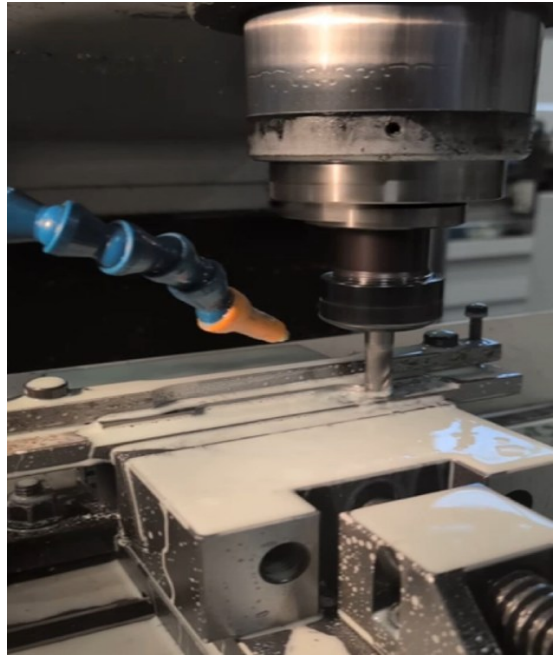


Figure 5

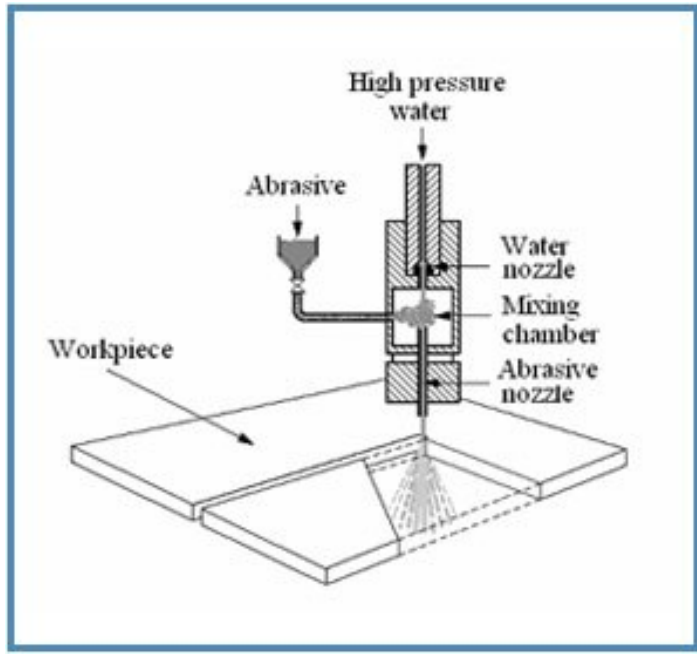


Figure 6— Alind (2025)

Figure 5 is an image taken during the milling process of the stainless steel samples. This shows the blanks mounted in the jig with the 12mm end mill in use and coolant. Figure 6 is in an illustration of the AWJ process.

3. Mechanical Testing

Figure 7 is the Mitutoyo stylus profilometer used to measure the surface roughness (Ra) values of the tensile specimens



Figure 7



Figure 8

In figure 8 the Tinius Olsen H50KS can be seen used to perform uniaxial tensile testing of the 304 stainless steel samples. A high-resolution camera system was used to track the elongation and strain throughout the test.

4. Data Processing

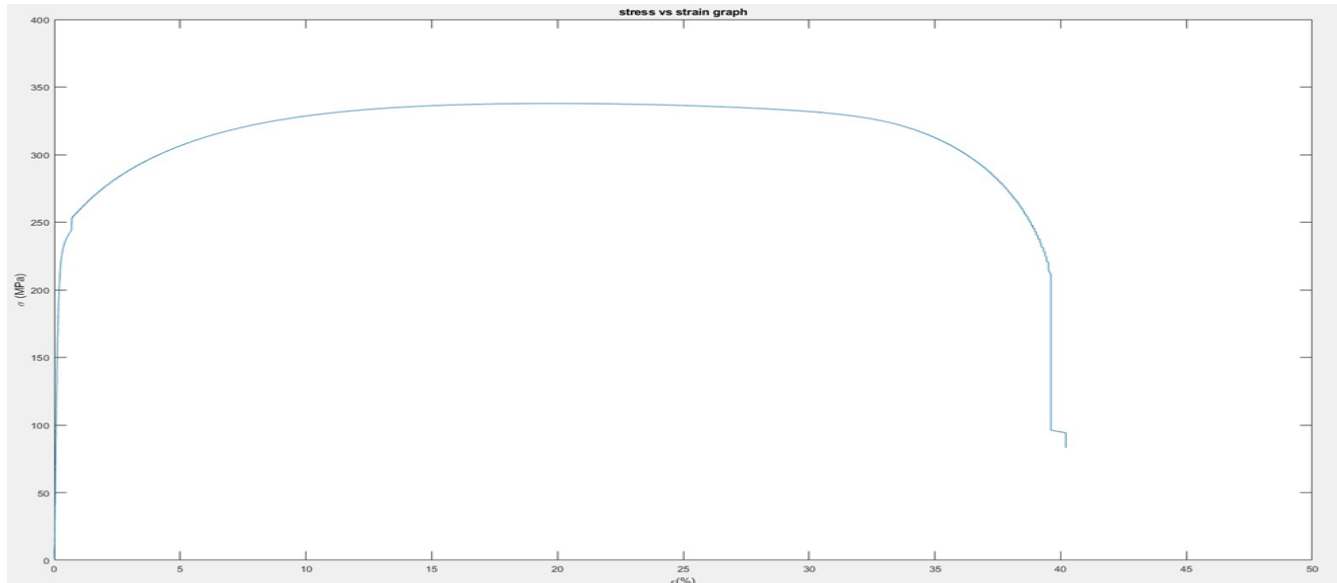


Figure 9

Figure 9 shows the stress vs strain graph of specimen 22.1 (CR4 mild steel). It exhibits several distinct regions that describe its mechanical behaviour under load, such as, UTS, yield point, proportional limit and fracture point.

Key Results

• Surface Roughness (Ra)

Milling improved surface finishes across all parameters, with the lowest Ra from large diameter tools at high speed/low feed. AWJ cutting showed rougher finishes, improving with slower traverse speeds. Seen in figure 10 for 304 stainless steel samples.

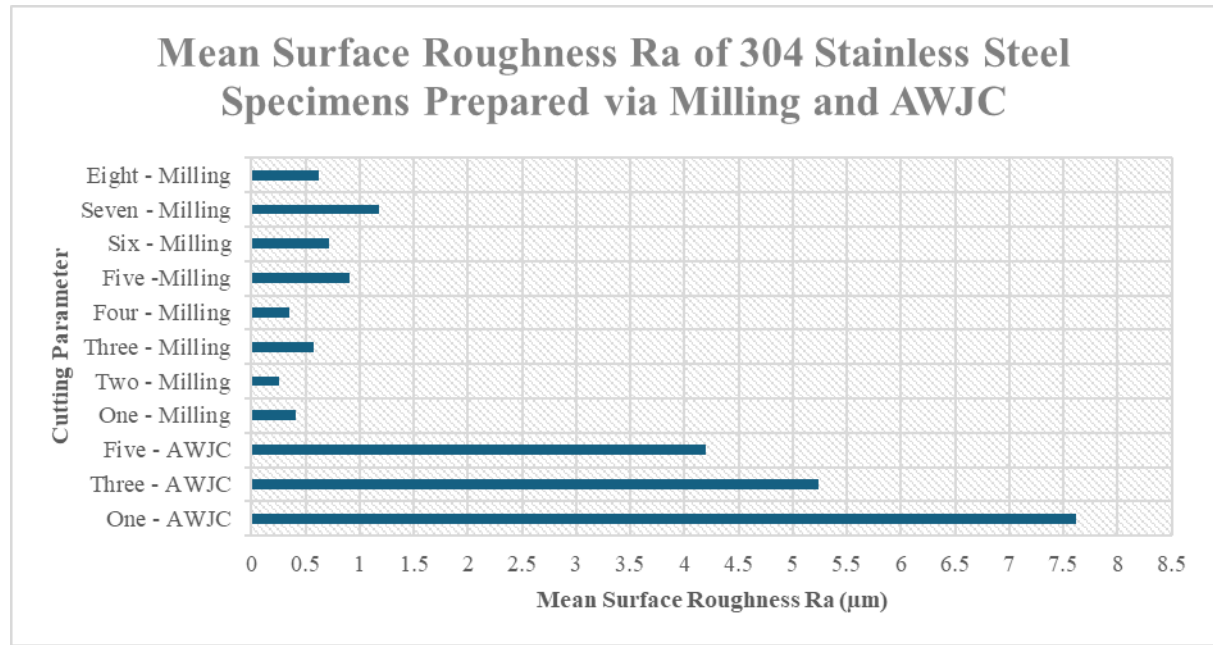


Figure 10

• Tensile Strength

Samples that were milled exhibited higher UTS and higher yield strength in both materials that were tested. This is due to residual stresses and work hardening induced by milling increasing the hardness of the material.

Machining Method	Young's Modulus (GPa)	Yield Stress (MPa)	UTS (MPa)	Uniform Elongation (%)
AWJ Cutter	125	232	328	23.3
Milling	113	237	342	19.5

Table 3— Average mechanical properties of CR4 mild steel from tensile testing

• Ductility

AWJ cutting is a cold cutting manufacturing process which reduces the thermal and mechanical stress when cutting materials. This increased the uniform elongation of the materials with CR4 mild steel showing a 4% increase.

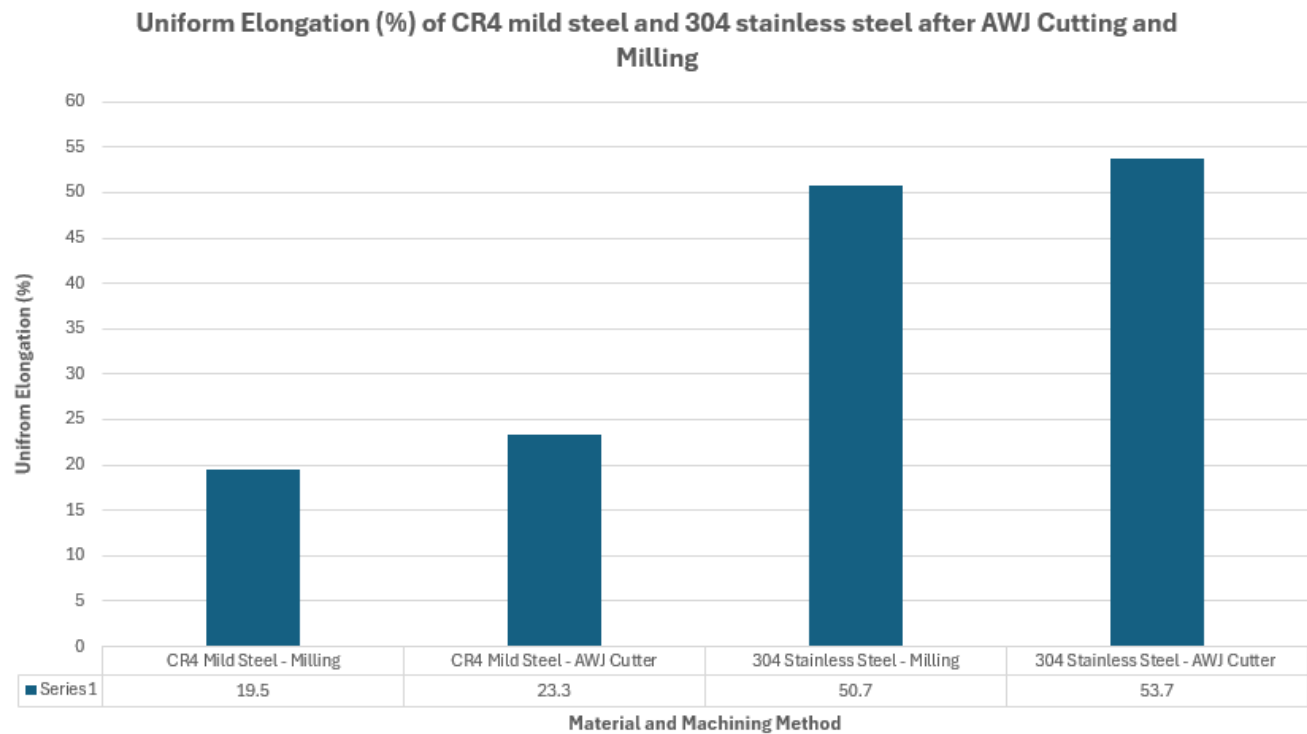


Figure 11

• Material Dependant Trends

While AWJ cutting preserved the ductility of both materials, 304 stainless steel responded differently, showing higher ductility and strength in milled specimens, opposed to CR4 results. This was contrary to the literature found in the research phase of the project.

Conclusion

Milling	AWJ Cutter
Superior dimensional accuracy	Faster profiling with minimal setup
Lower surface roughness across all materials	Higher surface roughness, reduced with slower feeds
Higher UTS and yield strength	Lower strength, but within acceptable engineering range
Induces residual stresses	Cold cutting, no heat affected zone
Reduced ductility	Higher ductility, especially in CR4
Slower machining process (15-30 mins per sample)	Quick cutting process (1-3 mins/sample)
Higher tooling and coolant cost	High abrasive consumption but less cost per sample.
Best for strength-critical and precision parts	Ideal for heat-sensitive, ductile, or complex parts
Best suited to final finishing after rough cutting	Should be used for rough profiling or minimal surface preparation