Optimal Band Saw Process Parameters

1 Contents

This project is made in collaboration with:

Funding:

INDUSTRIENS FOND

Industry partners:

MS INDUSTRITEKNIK ApS
Cnc service og reparation

1. Executive Summary

The optimal band saw process parameters project had the goal to find tendencies in Danish industry regarding metal band sawing. This is often an overlooked area of concern for the manufacturing industry, and the project sort to interview operators and operational management in their sawing process.

These interviews gave the project some direction, that there is the sentiment that the process is does not necessarily need parameter optimisation. Therefore, the test process took more of a theoretical approach rather than solving an industry application.

These tests showed that blade speed and feed can have significant impact on the MRR, straightness of cut and the chip formation. Additionally, if the saw is used in non-typical applications blade tip and breakage can occur.

2. Introduction

DAMRC would like to gain systematic insights into the cutting process of band sawing to detect if tendencies could be derived that could lead to strengthening the level of expertise on Danish soil. The suggestion will be to perform systematic tests of different material, blade types and cutting parameters to evaluate if tendencies can be detected and suggestions for how to overcome them can be derived from the project.

3. Pre-analysis

The subtractive process of cutting material into reasonable size by bandsaw is a neglected area of optimization. By feeding consistent straight cut material to the later machining operations, it will highly influence the part production time, material use and efficiency in the use of machinery according to Wu et al. (2018).

DAMRC occasionally get requests about challenges related to the band sawing processes at customers. However, the scientific literature is scarce and in general the market opinion seems to be that the process is “just” to cut without considering optimal parameters to reduce wear on the cutting blade, unnecessary wear on the machine, straightness of cut of the material (and hereby optimum use of material block).

4. Hypothesis

Sawing is seen as a simple process that has “one size fits all” solutions and has no room for optimization. Rather it is thought that if the process parameters are optimized for the specific cut, material removal rate can be improved.

5. Success Criteria

The criteria is to detect tendencies when cutting material at difference parameters and will be able determine proposals for improving the sawing process.

6. Project Scope/ description

The subtractive process of band sawing is currently not an area for which DAMRC has a lot of data about market size and typical suppliers. Therefore, a market assessment will act as a foundation for this project.

Based on the market understanding DAMRC will organize tests of up to three different materials reflecting the use in industry and process parameters that enable as many people as possible to be able to use the insights created.

After tests, inspection, and measurements of test specimens the evaluation will show if tendencies are present, and if it will make sense to generate a “reference” book for cutting conditions that can serve as a reference in future requests and services for customers.
DAMRC will use the available CNC-bandsaw equipment that is already placed at DAMRC.

7. Risk Analysis

If no tendencies can be observed in the test specimens it will be valued as an insight. The expectations by having three different materials are that tendencies can be provoked when having different materials and different blade types.

8. Literature Study

8.1 Introduction

In the realm of industrial machining, metal sawing stands out as a pivotal process, serving as the bedrock for shaping metal workpieces with precision and versatility.

As the start of the project existing literature and articles have been reviewed to base the project on existing state-of-the-art knowledge and insights. This knowledge is gained through scientific articles as well as user guides provided by saw blade and machine suppliers.

8.2 Types of Saws

There are various types of saws used in the metal work industry, and sawing is a common machining process used to cut metal workpieces into desired shapes and sizes. Different types of metal saws are employed for various applications, each with its unique characteristics. Here is a brief technical introduction to the mentioned types:

8.2.1 Horizontal Band Saw

A horizontal band saw is a cutting tool with a continuous band of toothed metal rotating on two wheels in a horizontal plane. It is suitable for cutting long workpieces and is often used for straight or mitre cuts.

Horizontal band saws are efficient for cutting various metals and are particularly useful for large-scale metal fabrication. Horizontal band saws are excellent for cutting large and heavy metal pieces, such as steel beams. They provide stability and precision for straight cuts in large workpieces and are commonly employed in structural steel fabrication. (Fu, 2023)

Figure 1: Horizontal Band Saw

8.2.2 Vertical Band Saw

Unlike horizontal band saws, vertical band saws have a blade that moves in a vertical direction.
They are versatile and can handle intricate cuts, curves, and irregular shapes in smaller workpieces.
Vertical band saws are commonly used in workshops where precision and flexibility in cutting are essential.

Figure 2: Vertical Band Saw

8.2.3 Circular Saw

Circular saws are versatile cutting tools that use a toothed blade to make straight or angled cuts through various materials, including metal.

Circular saws are equipped with circular blades. (Brüggemann, 2022)

Figure 3: Circular Saw

8.2.4 Abrasive Saw

An abrasive saw, also known as a cutoff saw or chop saw, uses abrasive wheels to cut through metal. The cutting wheel is composed of abrasive particles bonded together, and it grinds through the metal as it rotates.

Abrasive saws are versatile and can handle a variety of metals, but they may produce more heat and generate more burrs compared to cold saws. They are suitable for applications where the finish quality is less critical, and the focus is on efficient material removal, like cutting stock material for further processing.

Figure 4: Abrasive Saw

8.2.5 Cold Saw

A cold saw is a circular saw designed for cutting metals at lower temperatures, minimizing heat generation during the cutting process. It utilizes a high-speed, toothed blade that operates at a slower rotational speed compared to traditional saws, reducing friction and heat.

Cold saws are often used for precision cutting of ferrous and non-ferrous metals and are suitable for applications requiring clean and burr-free edges. Cold saws are ideal for applications where high precision and a smooth finish are crucial, such as cutting tubes for automotive or aerospace components. The cold cutting process minimizes heat-affected zones, preserving material properties.

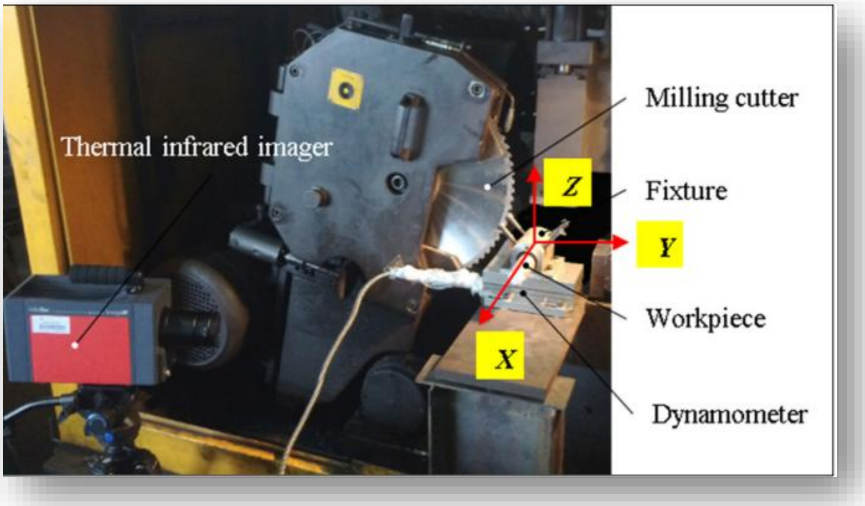


Figure 5: Cold Saw used in these milling temperature trials

8.3 Types of Band Saws Blade

8.3.1 Bi-Metal Saw Blades

Bi-metal band saw blades cover the broadest range of sawing applications. It is constructed from two different types of metal, typically high-speed steel (HSS) and a flexible, tough backing material like alloy steel. They can cut carbon steel, tool steel, structural steel, stainless steel, pipes/tubing, die steel, angles, flat stock, and mixed metal applications. (detroitbandsaw, 2024)

Figure 6: Bi-Metal Saw Blade

8.3.2 Carbon Steel Saw Blades

Carbon steel blades are made entirely of carbon steel, and they an cut the following: mild steels, copper, wood, plastic, cast iron, cork, brass, lead, furniture, resawing projects, bronze, zinc, fiberglass, and non-ferrous metals. Simply the differences between the blades are clearly indicated by their names.

Figure 7: Carbon Steel Saw Blades

8.3.3 Carbide Saw Blades

These blades have carbide tips along the cutting edge. They are used to cut case hardened steels, spring steels, high speed steels, nickel-based alloys, case hardened steels, composite graphite, high nickel alloys, titanium, inconel, and other exotic metals.

Figure 8: Carbide Saw Blade

8.4 Types of Band Saws - Teeth

8.4.1 Regular Tooth Blades

A common tooth pattern, regular tooth bandsaw blades feature straight teeth with deep gullets, often with a straight rake. This tooth pattern is suited for both contour and cut-off cutting. It is a general-purpose metal cutting blade for thin materials including metals and wood. (handymansworld., 2024)

8.4.2 Hook Tooth Blades

This type of blade has sharp teeth that look like the shape of a hook. These larger teeth are widely spaced and feature an undercut face with a 10° rake angle. This teeth type will produce more coarse cuts. It can also be used for longer cuts due to the deep gullet and rake angle allowing more of the cut material to be moved aside. A hook-tooth blade is best suited for hard, nonferrous alloys and hardwoods.

8.4.3 Skip Tooth Blades

Like hook teeth blades, these types of blades have widely spaced teeth and reduce clogging when using materials like softwoods, plastics, or nonferrous metals. This type of blade has a shallow gullet and a 90° tooth angle that allows the chips to come out cleanly, but the widely spaced teeth pattern makes it difficult to produce a smooth finish.

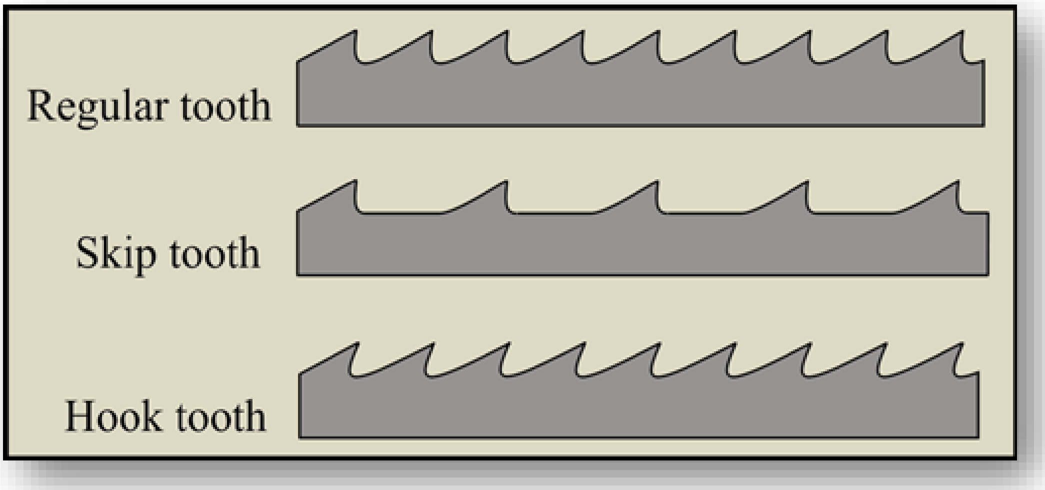


Figure 9: Visual of tooth types, regular, skip and hook tooth

8.4.4 Variable Pitch Blades

This tooth pattern involves a variety of teeth in different sizes and settings. The varying angles and gullet depths reduce the vibrations, making this blade perfect for smooth but fast finish cuts and ideal for cutting curves and contouring.

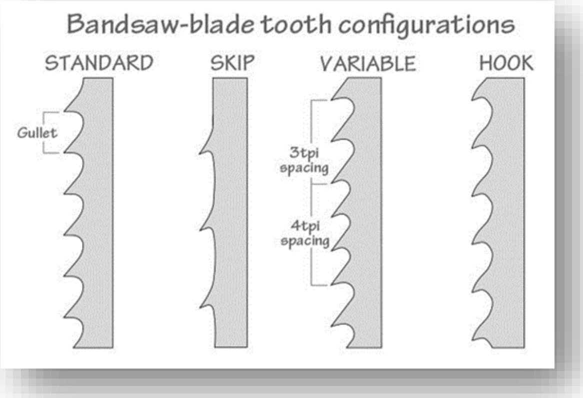


Figure 10: Visual of tooth types, variable tooth

8.4.5 Wavy Tooth Blade

A wavy tooth blade, also known as a variable pitch or skip-tooth blade, is used in band sawing for specific cutting applications where a balance between speed and precision is required. The wavy tooth pattern on this type of blade alternates between large and small gullets, providing effective chip removal during cutting. This design minimizes the likelihood of the blade binding or clogging, especially when cutting softer materials or resins that tend to create more sawdust.

The varied pitch also reduces vibrations, resulting in smoother and more efficient cuts. Wavy tooth blades are often favoured when versatility in cutting different materials is necessary, allowing for a good compromise between cutting speed and the ability to handle various workpieces with different characteristics.

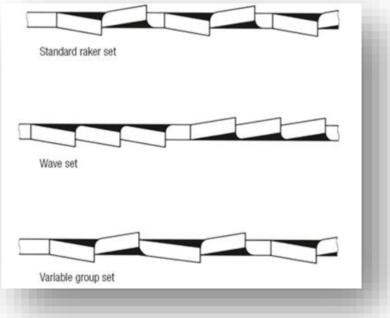


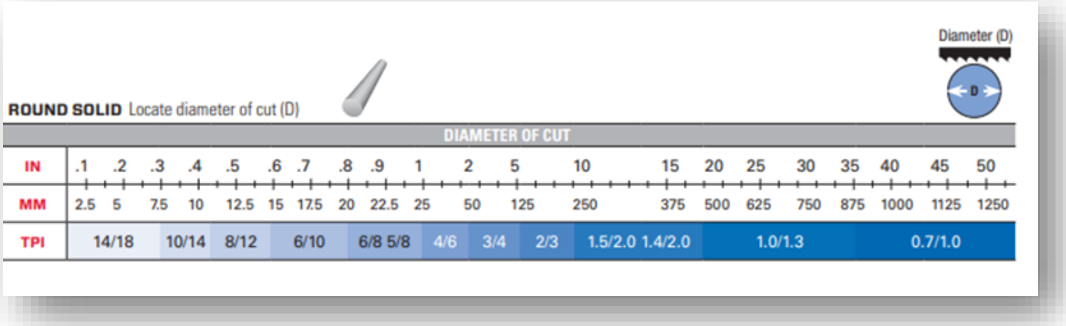
Figure 11: Visual of tooth rake types

8.5 Blade Selection

8.5.1 TPI (Teeth Per Inch)

TPI, or Teeth Per Inch, is a critical parameter used to describe the density of teeth on a saw blade. It represents the number of cutting teeth within one inch of the blade. The TPI value is crucial in determining the appropriate saw blade for a particular cutting application. (Lenox, 2024)

Selecting the right TPI for a saw blade is essential for achieving optimal cutting performance. Different TPI values are suitable for various materials and applications.



ROUND SOLID Locate diameter of cut (D)

DIAMETER OF CUT

IN .1 .2 .3 .4 .5 .6 .7 .8 .9 1 2 5 10 15 20 25 30 35 40 45 50

MM 2.5 5 7.5 10 12.5 15 17.5 20 22.5 25 50 125 250 375 500 625 750 875 1000 1125 1250

TPI 14/18 10/14 8/12 6/10 6/8 5/8 4/6 3/4 2/3 1.5/2.0 1.4/2.0 1.0/1.3 0.7/1.0

Figure 12: Example of a TPI chart

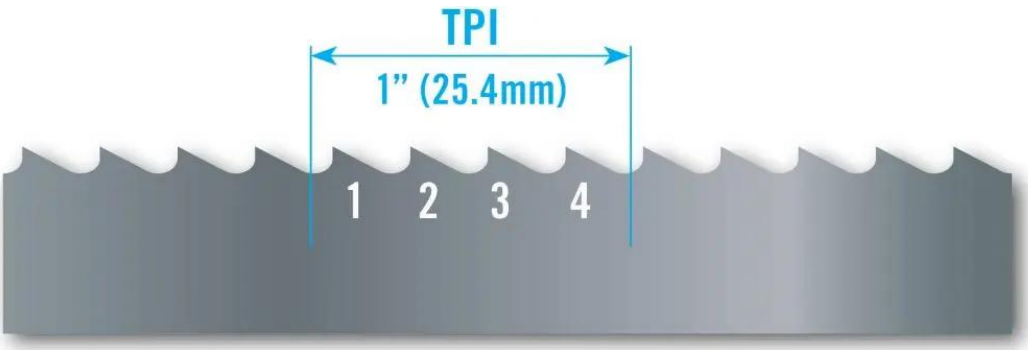


Figure 13: Visual representation of TPI

8.6 Feed and Speed

In metal cutting, speed and feed are critical parameters that impact the efficiency, tool life, and quality of the cut. Understanding these factors is essential for selecting the right cutting tools and optimizing machining processes.

8.6.1 Speed

Speed, often expressed in surface feet per minute (SFPM) or meters per minute (m/min), refers to the linear speed at which the cutting tool moves across the workpiece. The speed directly influences tool wear, heat generation, and the quality of the cut. It is a crucial factor in determining the overall machining performance.

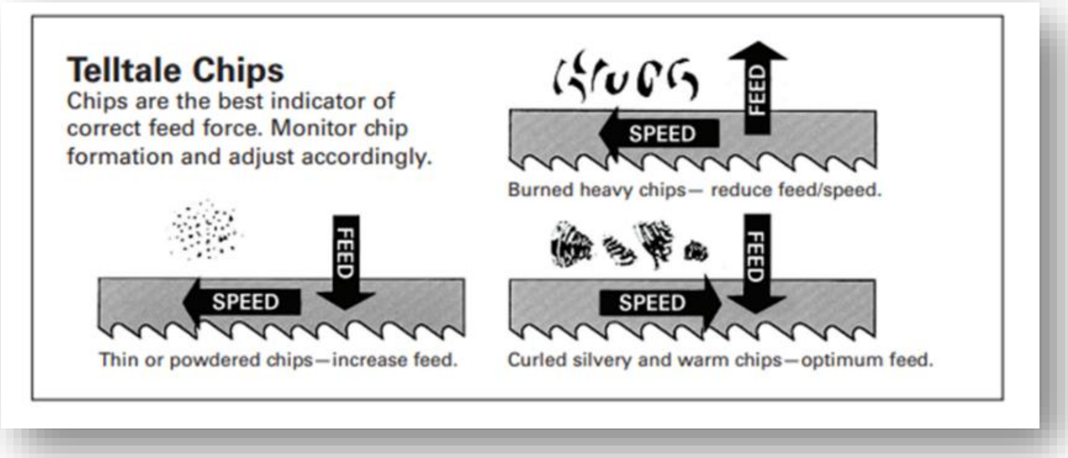


Figure 14: Visual of feed and speed in sawing

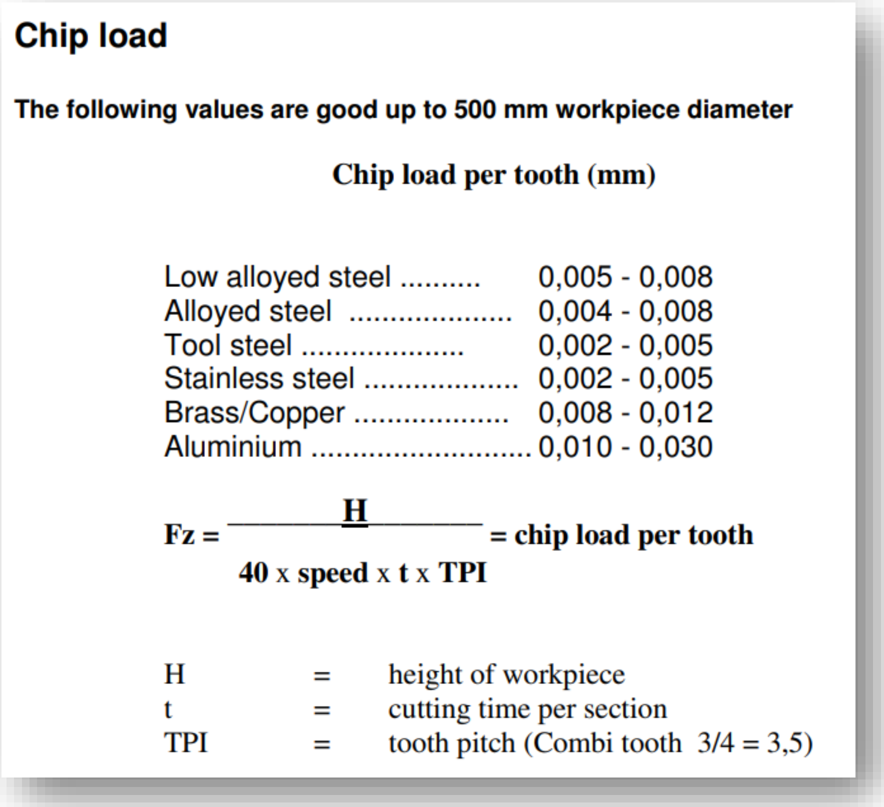
8.6.2 Feed

Feed, typically measured in inches per tooth (IPT) or millimetres per tooth (mm/tooth), represents the distance the cutting tool advances into the workpiece during one revolution.

Feed rate affects the chip size, tool life, and surface finish. It plays a significant role in controlling the material removal rate and preventing issues such as tool breakage or excessive tool wear.

8.7 Chip Per Tooth

Chip per Tooth (CPT) is a crucial parameter in sawing processes, especially in metal cutting applications. It refers to the size or volume of the chip produced with each revolution of the saw blade or each tooth engagement with the workpiece. Using the time variable in the chip load equation can guide the operator to a maximal feed rate to run the blade at. (Roentgen, 2024)



Chip load

The following values are good up to 500 mm workpiece diameter

Chip load per tooth (mm)

Low alloyed steel	0,005 - 0,008
Alloyed steel	0,004 - 0,008
Tool steel	0,002 - 0,005
Stainless steel	0,002 - 0,005
Brass/Copper	0,008 - 0,012
Aluminium	0,010 - 0,030

$$Fz = \frac{H}{40 \times speed \times t \times TPI} = \text{chip load per tooth}$$

H = height of workpiece
t = cutting time per section
TPI = tooth pitch (Combi tooth 3/4 = 3,5)

Figure 15: Chip load chart

8.8 Chips

Chip diagnosis in metal band sawing is a crucial aspect of optimizing cutting performance and ensuring the longevity of both the blade and the machinery. Monitoring the characteristics of the chips produced during the cutting process provides valuable insights into the cutting conditions.

The sawing should generate continuous, curled chips that are uniform in size and colour. Changes in chip colour, size, or the presence of irregularities may signal issues such as incorrect blade speed, inadequate coolant, improper blade tension, or the need for blade replacement.

Regularly analysing the chips allows operators to diagnose and address potential problems promptly, optimizing cutting efficiency, extending blade life, and maintaining the overall effectiveness of the metal band saw.

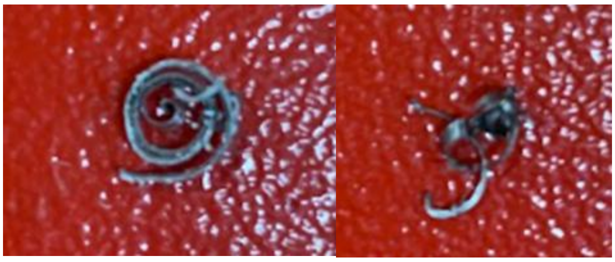
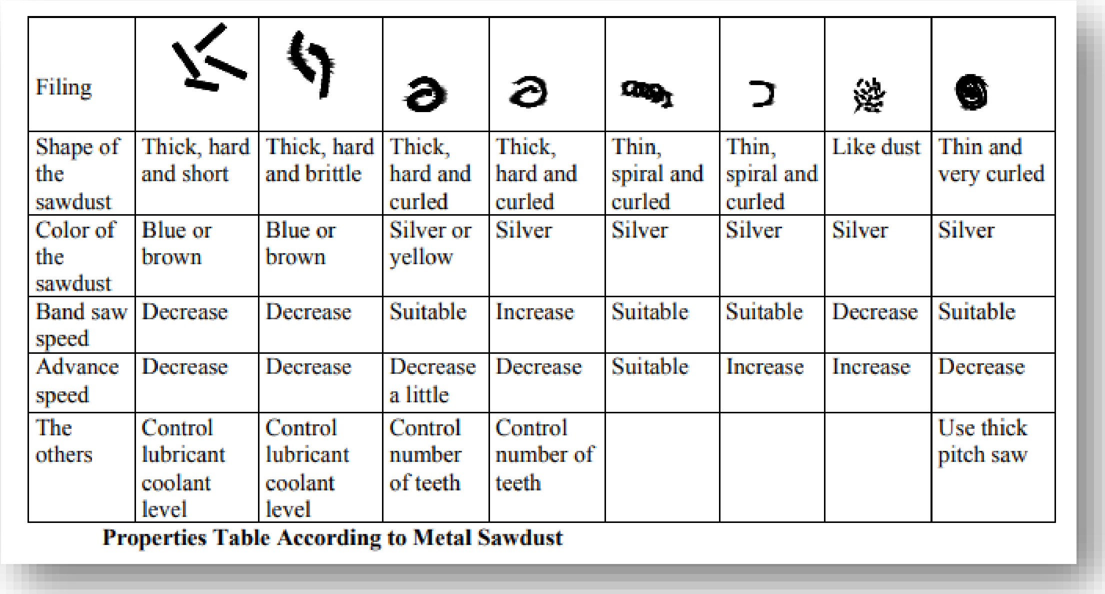


Figure 16: Chips from tests



Filing								
Shape of the sawdust	Thick, hard and short	Thick, hard and brittle	Thick, hard and curled	Thick, hard and curled	Thin, spiral and curled	Thin, spiral and curled	Like dust	Thin and very curled
Color of the sawdust	Blue or brown	Blue or brown	Silver or yellow	Silver	Silver	Silver	Silver	Silver
Band saw speed	Decrease	Decrease	Suitable	Increase	Suitable	Suitable	Decrease	Suitable
Advance speed	Decrease	Decrease	Decrease a little	Decrease	Suitable	Increase	Increase	Decrease
The others	Control lubricant coolant level	Control lubricant coolant level	Control number of teeth	Control number of teeth				Use thick pitch saw

Properties Table According to Metal Sawdust

Figure 17: Chip visual diagnosis

8.9 Visual Inspection of the Blade Wear

Tool wear in bandsaw blades can occur due to various factors, and it can significantly affect the blade's performance and longevity. Here are some examples of tool wear in bandsaw blades along with their causes:

8.9.1 Tooth Wear

Tooth wear is a common type of wear in bandsaw blades. It can manifest in different forms:

- Attrition: Gradual wearing down of the cutting edge due to friction with the workpiece.
- Abrasion: Wear caused by the abrasive nature of the material being cut.

Edge Chipping: Small chips or fractures on the cutting edge of the tooth due to impacts with hard or irregularly shaped materials.

Causes
Cutting abrasive materials such as metals with hard particles or materials with impurities. Improper blade speed or feed rate, leading to excessive friction and heat generation. Inadequate blade tension, which can cause teeth to rub against the workpiece instead of cutting cleanly.

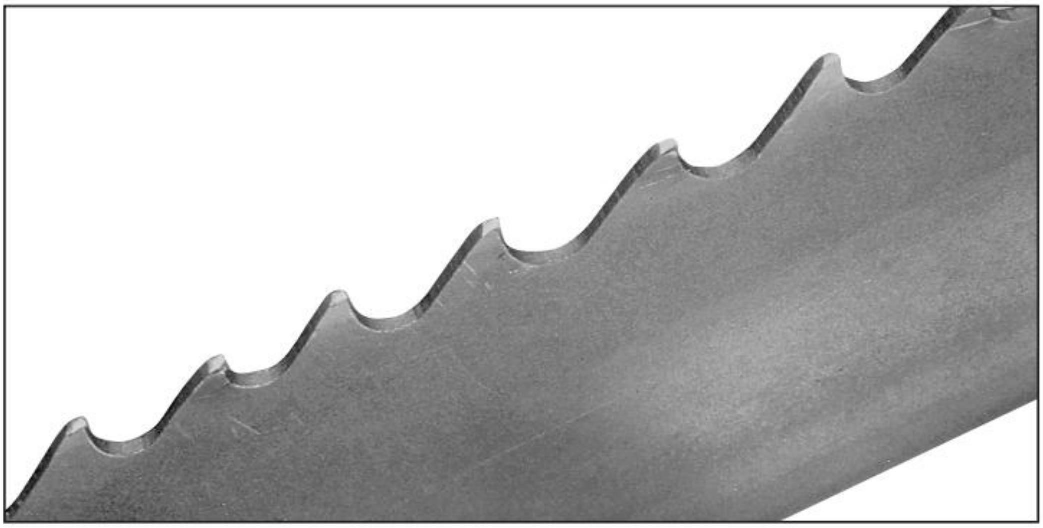


Figure 18: Heavy wear on tips and corners of teeth

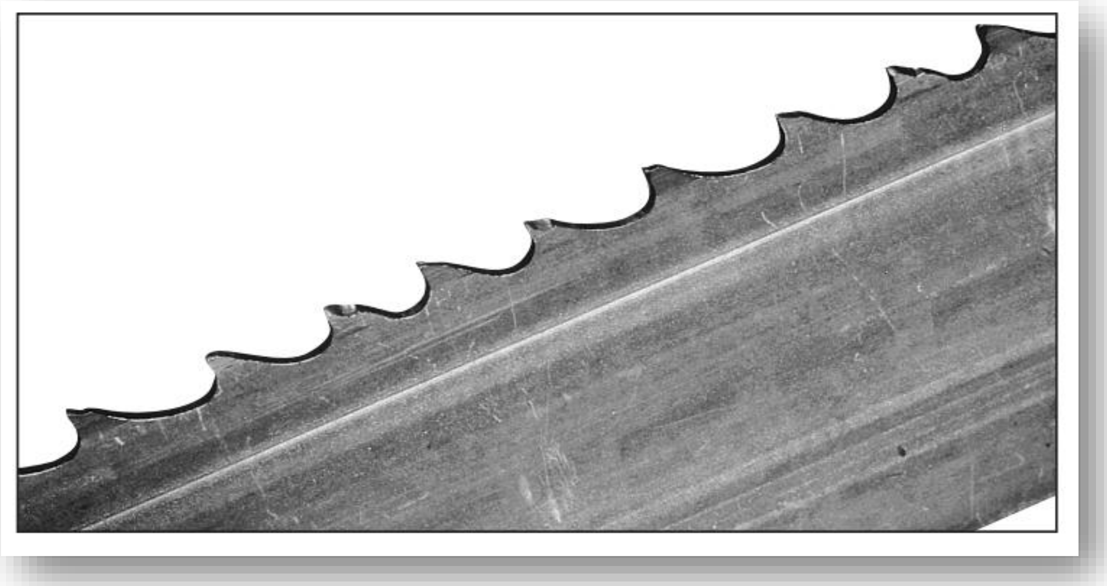


Figure 19: Chipped or broken teeth

8.10 Straightness of Cut

To reduce material waste and reduce the need for more than necessary processes after sawing, straightness is an indicator of quality of cut. Research has been conducted into straightness of cut in Inconel 718, measured using a ZEISS Duramax coordinate-measuring machine. (Diebold, 2021)

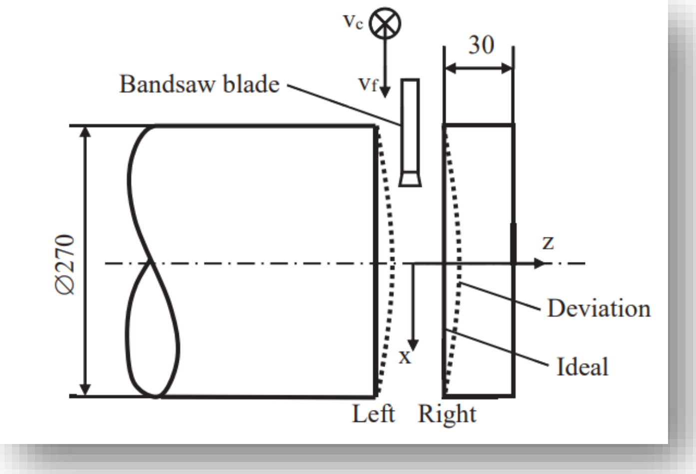


Figure 20: Diagram of how the deviation in straightness is measured

8.11 Parameters

Parameter optimisation is an area of interest in band sawing. This has been conducted through interviews with operators and operational supervisors of band saw cutting. The measured values are matched against the manufacturer recommendations. (Sucksdorff, 2023)

As this is similar to the approach we seek to take, these studies results are interesting and conclude as follows:

"In the conducted interviews with three operators and one supervisor, the first phase revealed some discrepancies in their responses. All agreed that sawing parameters are initially chosen from lists provided by the manufacturer, specific to different saw blades.

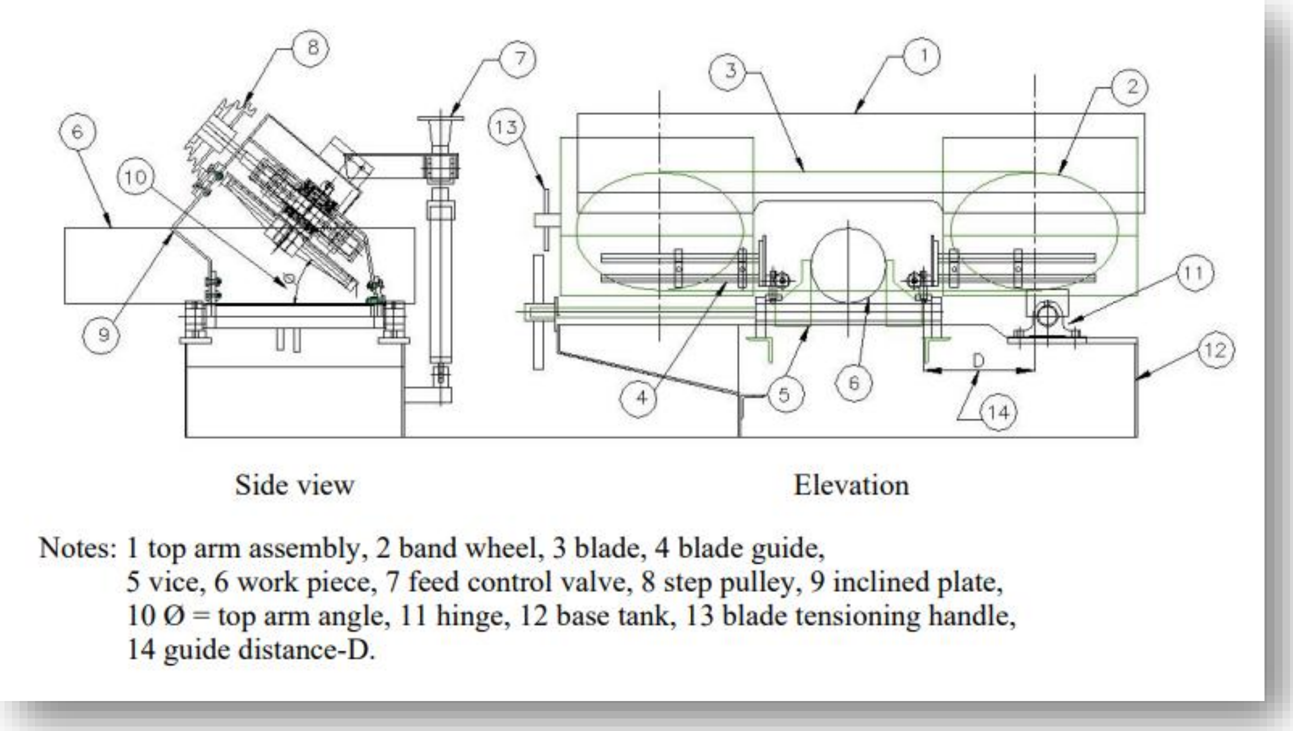
However, there was some confusion about which list corresponds to each blade. Operators later admitted to adjusting the values based on their preferences. A major concern was a loud squeaking noise, addressed by reducing the saw blade speed. Ridges on the cutting surface were considered a cosmetic issue rather than affecting blade life. Material variations, particularly with S355 steel, were noted to impact noise levels. The discussion also touched upon the saw blade life cycle influencing parameters, with varying perspectives among operators. The second phase delved into saw blade changing, emphasizing the use of sensors to monitor deviation and pressure for indications of wear.

Cutting hours for blade change ranged from 10 to 50 hours. The final phase explored factors affecting the process, with operators dismissing seasonal changes but acknowledging awareness of lubrication mixtures. Operators showed consistency in their approach to different saw blades, relying on lists and adjusting values based on noise and surface roughness.

The supervisor highlighted potential issues related to blade change, swarf brush adjustment, and blade guidance rollers assembly. Overall, the operators reported a relatively smooth process with occasional challenges, especially with specific materials like S355 steel and pipes."

Research has been conducted on the development of a semi-empirical model for predicting the Material Removal Rate in band sawing using dimensional analysis. This is also the base frame for further testing in this project. The proposed model aims to integrate the key process, material, and machine parameters into a unified predictive framework.

By leveraging the principles of dimensional analysis, the model seeks to establish a functional relationship between these variables, offering a more comprehensive understanding of their influence on MRR. This approach not only enhances the accuracy of MRR predictions but also provides valuable insights into the underlying mechanisms governing the sawing process. (Mewada, 2018)



Notes: 1 top arm assembly, 2 band wheel, 3 blade, 4 blade guide,
5 vice, 6 work piece, 7 feed control valve, 8 step pulley, 9 inclined plate,
10 Ø = top arm angle, 11 hinge, 12 base tank, 13 blade tensioning handle,
14 guide distance-D.

Figure 21: Schematic of the bandsaw relative to the formula variables

Using dimensional analysis, the model is formulated based on experiments conducted using Taguchi's technique. The study identifies feed, speed, and top arm angle as significant parameters, with feed having the highest significance at 58%, followed by speed (17.44%) and top arm angle (13.55%).

$$MRR = AFd^2\left(\frac{D}{d}\right)^{a1}\left(\frac{S}{F}\right)^{a2}\left(\frac{\rho F^2}{T}\right)^{a3}\left(\frac{Ys}{T}\right)^{a4}\theta^{a5}$$

Tension and blade guide distance are found to have less significance on MRR. The developed model indicates that feed, speed, and top arm angle are directly proportional to MRR, aligning with the experimental analysis where an increase in these parameters results in an increase in MRR. The predicted MRR values from the model closely match the experimental results, and the model's validity is confirmed through calculations of mean error, root mean square error, and percentage average error, which fall within an acceptable range.

The research is considered novel as there is a lack of conclusive investigations in the open domain regarding the application of dimensional analysis in band sawing operations. Furthermore, the study introduces parameters like top arm angle, blade guide distance, and blade tension, which have not been extensively investigated previously. The authors suggest future investigations could explore the effects of different workpiece materials, shapes, and other process parameters on MRR.

8.12 Conclusion on the Pre-Analysis and Literature Study

In conclusion, metal sawing emerges as a fundamental machining process, offering versatility and precision in shaping metal workpieces for a myriad of applications. The various types of metal saws each bring unique characteristics to the table, catering to specific needs within the realm of metalworking. This technical overview has shed light on key saw types, blade variations, teeth configurations, and parameters influencing the sawing process.

Diversity in Metal Sawing
The exploration of diverse saw types, from the precision-driven Cold Saw to the versatile Circular Saw and robust Horizontal Band Saw, underscores the adaptability of metal sawing to different industrial requirements. The Vertical Band Saw introduces a vertical dimension, adding flexibility for intricate cuts in smaller workpieces.

Blade Technology
Understanding the intricacies of band saw blades becomes pivotal in optimizing performance. Whether it is the broad applicability of Bi-Metal Saw Blades, the material-specific attributes of Carbon Steel Saw Blades, or the cutting-edge capabilities of Carbide Saw Blades, the choice of blade material directly influences the efficiency and outcome of the cutting process.

Tooth Configurations
The insight into various tooth configurations, including Regular, Hook, Skip, Variable Pitch, and Wavy tooth blades, demonstrates the nuanced selection available for different cutting requirements. Each tooth pattern aligns with specific applications, balancing between coarse cuts, smooth finishes, and adaptability to diverse materials.

Critical Parameters
Examining critical parameters such as Teeth Per Inch (TPI), Speed, Feed, and Chip Per Tooth (CPT) underscores the meticulous considerations essential for optimal sawing performance. The TPI chart serves as a guide for selecting the right blade density, while managing speed and feed ensures efficiency, tool longevity, and high-quality cuts.

Real-world Challenges and Innovations
Insights from research on sawblade lifespan and material removal rate highlight the practical challenges faced by operators. The adjustments made based on noise, surface roughness, and material variations underscore the need for a nuanced approach. The introduction of a prediction model for Material Removal Rate using dimensional analysis adds an innovative perspective, offering a scientific framework for optimizing sawing parameters.

In essence, the field of metal sawing is not only rich in its array of technologies but also dynamic in its response to real-world challenges. As technological advancements continue, the integration of innovative models and a deeper understanding of parameters will play a pivotal role in shaping the future landscape of metal sawing. This comprehensive overview sets the stage for informed decision-making, paving the way for enhanced efficiency and precision in metal cutting operations.

9. Industry Interviews

9.1 JP Group

An interview conducted with Jesper Knudsen from JP Group sheds light on their band saw usage and practices. JP Group, dealing with the production of spare parts for vintage cars, relies heavily on circular saws for cutting thin tubes ranging from 20-200mm in diameter. They operate several saws, primarily older models from the 1970s and 1980s, lacking computer control.

Their sawing process involves non-educated young operators supervised by a senior employee, sometimes leading to issues like improper blade changes and increased burring, which subsequently prolongs deburring time. Saw blades are changed infrequently and re-ground at low cost, with a typical tooth per inch (TPI) range of 4-6. Changes occur when transitioning between steel types, and cutting fluid, a mix of water and oil, is inconsistently applied with no precise measurements.

Notably, there's a lack of continuous quality control or maintenance tracking for the saws, highlighting potential areas for improvement in efficiency and product quality.

9.2 Fagerlunds Værktøjs- og Metalvarefabrik A/S

Fagerlunds Værktøjs- og Metalvarefabrik A/S faces a significant challenge in their production process: achieving burr-free cuts while maintaining a high output of 15 tons per year. To meet this challenge, they rely on a CNC saw, specifically the Pedrazzol model, equipped with an oil mist spray system to ensure chip cleanliness during cutting operations. The materials used in their production include 16 lengths welded together, which are then cut into 35x15mm flat bars, with an annual production volume of approximately 150,000 pieces.

Figure 22: Sixteen sections of flat bar stacked together via welding

One notable advantage of their CNC saw is its ability to cut stainless steel pipes without the need for blade changes, demonstrating versatility and efficiency in handling different materials. Additionally, the company employs a separate blade for cutting aluminium extrusion, indicating a specialization to meet specific material requirements.

Figure 23: Pedrazzol CNC band saw

However, operational issues persist despite the advanced equipment. The company faces challenges such as blade break-in time and occasional cracking, which can lead to downtime and impact productivity. Moreover, the condition of the cut is determined by empirical factors such as chip appearance and cutting time, rather than precise measurement methods.

An operational threshold exists, where if the stack height exceeds 16, cuts may deviate from tolerance limits, highlighting the importance of maintaining optimal operating conditions. Maintenance practices at Fagerlunds Værktøjs- og Metalvarefabrik A/S include occasional servicing over a two-year period, often involving PLC board and motor replacements. However, a lack of preventive maintenance procedures is evident, with daily cleaning being the primary upkeep method.

Furthermore, management of blades and coolant poses challenges, with infrequent checks conducted primarily during blade break-in periods. Blade changes are prompted by observable changes in cutting times and feed rates, suggesting a reactive approach to maintenance rather than a proactive one.

Figure 24: Oil mist lubricant used

Figure 25: Blade and fences are kept well cleaned

In conclusion, addressing the identified operational challenges is crucial for optimizing efficiency and productivity in sawing operations at Fagerlunds Værktøjs- og Metalvarefabrik A/S. Improvements in maintenance practices, process monitoring, and equipment reliability can be avenues of interest to them.

10. Experiment Design

10.1 Test 1

10.1.1 Introduction

Determining the minimum test cut thickness is a critical step in optimizing the precision and efficiency of metal cutting processes. A widely accepted rule of thumb guiding this determination is that the minimum test cut thickness should be at least three times the blade kerf—the width of material removed during each cut. This guideline serves as a practical benchmark to ensure that the blade has sufficient clearance to operate effectively, minimizing the risk of binding or excessive wear.

By adhering to this rule, operators can fine-tune their cutting parameters to achieve optimal results, striking a balance between precision and the avoidance of potential blade-related issues. This introduction sets the stage for a methodical approach to test cutting, emphasizing the importance of this initial step in achieving accurate and reliable results in metalworking applications.

10.1.2 Test Design/Process

The test design and process included:

- Evaluation of a ø140mm round bar, then 110x110mm square bar.
- Three tests conducted using different blade thicknesses: two times and one times the standard blade kerf.
- Recorded parameters: feed rate, cutting speed, and time to cut.
- Objective: Assess the impact of varying blade thicknesses on cutting performance

10.1.3 Equipment for the Test

Tests are performed on a Karmetal osa 350 x 450 CNC band saw.

Figure 26: Karmetal osa 350 x 450

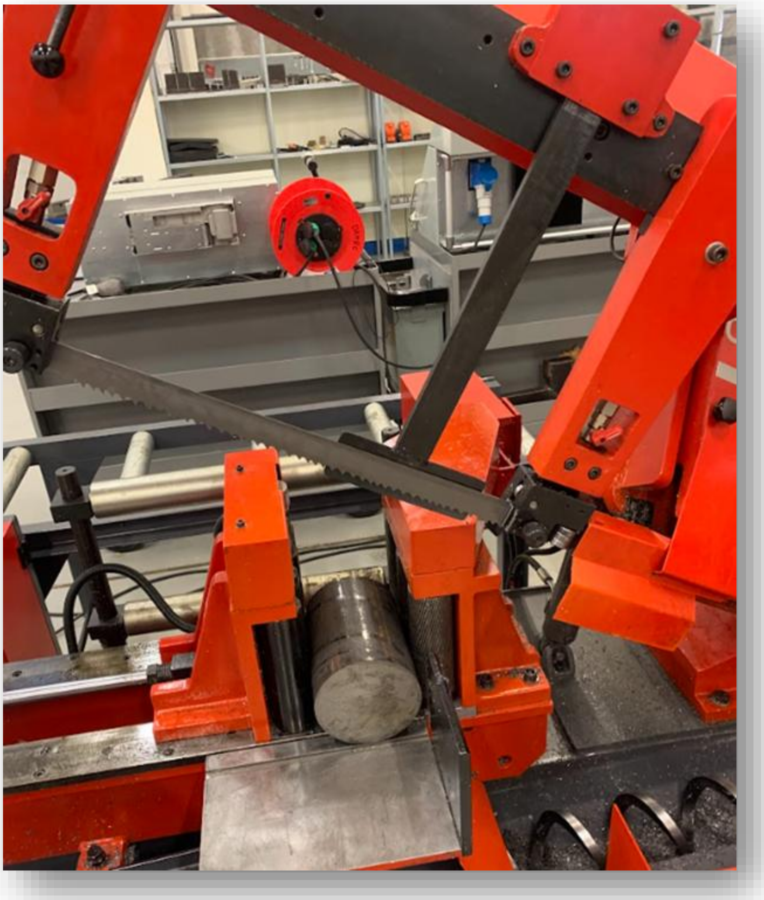


Figure 27: Test performed on the round bar

Figure 28: Test performed on the square bar

10.1.4 Material for the Test

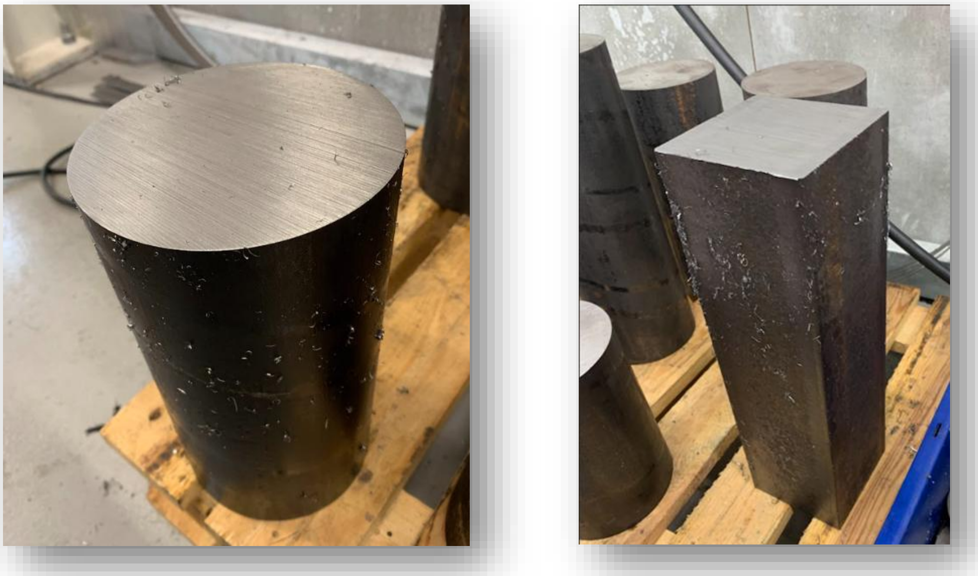


Figure 29: Steel round and square bar

10.1.5 Conduction of the Test

Table 1: Test parameters on the round bar

	Cut 01	Cut 02	Cut 03
Cut thickness (mm)	4	2,8	1,4
Cutting speed (Mt/min)	75	80	80
Time to Cut (min)	5,25	5,08	5,20
Feed Dial	2	2	2

Table 2: Test parameters on the square bar

	Cut 01	Cut 02	Cut 03
Cut thickness (mm)	4	2,8	1,4
Cutting speed (Mt/min)	80	80	80
Time to Cut (min)	6,18	2,40	5,01
Feed Dial	2	5	2

10.1.6 Test 1 - Conclusion

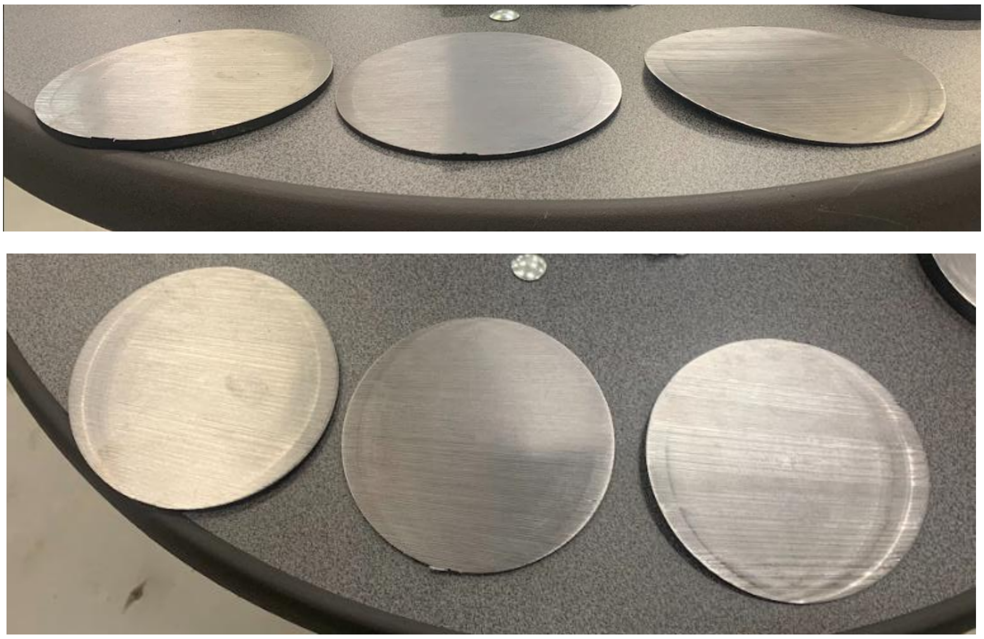


Figure 30: Visual of cuts three, two and one times blade kerf on round bar

The warpage seen in the tests done with a width less than three times that of the kerf, confirms the rule of thumb that this is minimum thickness one can cut on this type of saw.

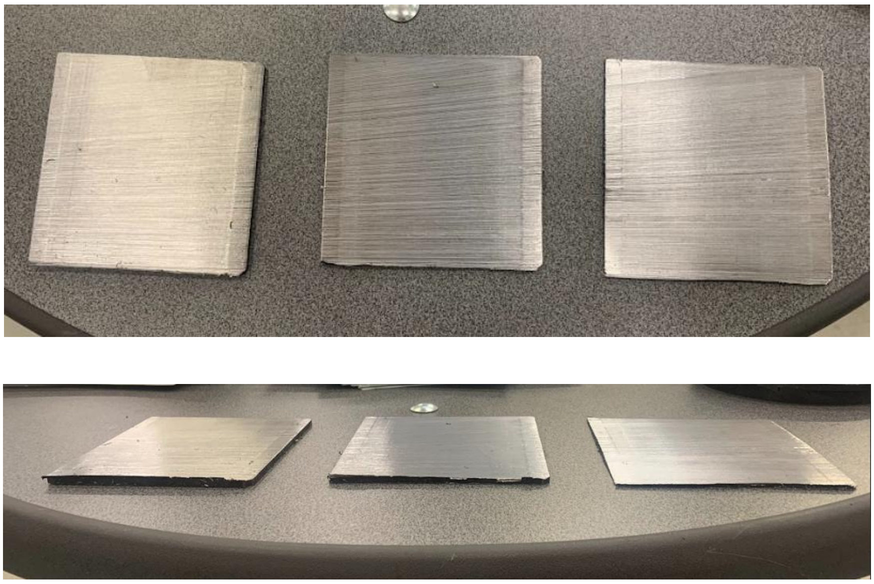


Figure 31: Visual of cuts three, two and one times blade kerf on square bar

This test shows that square bar shows the same trend, warpage seen in the tests done with a width less than three times that of the kerf, confirms the rule of thumb.

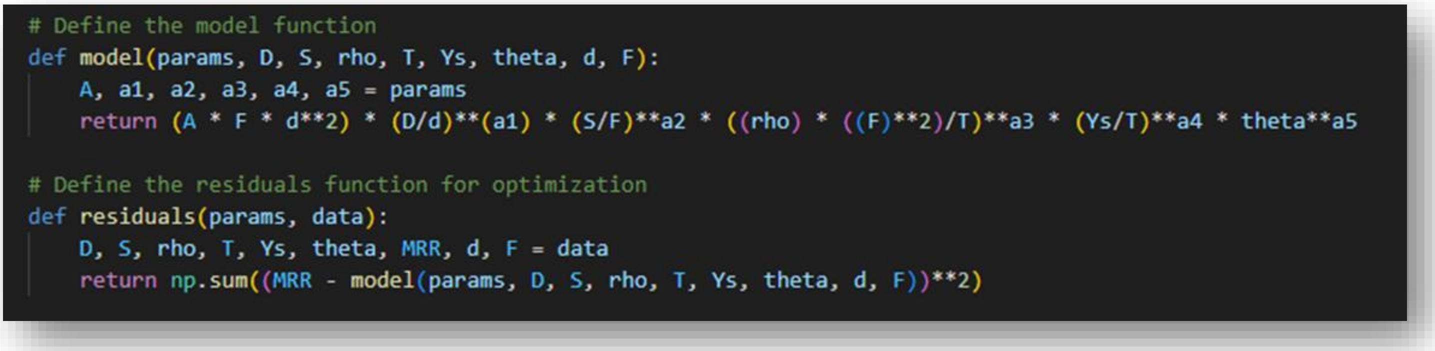
10.2 Test 02

10.2.1 Introduction

Test 2 seeks to explore the optimization of MRR by comparing the actual performance of the band sawing process against a theoretical model. This comparison is intended to identify the gaps between theoretical predictions and empirical outcomes, providing insights into the limitations of existing models and the potential for improvement. By systematically varying key process parameters and measuring their impact on MRR, this test seeks to validate the theoretical model and assess its accuracy under different operating conditions.

The model seeks to use the formula investigated by (Mewada, 2018).

Constants are calculated with a python code:



```python
# Define the model function
def model(params, D, S, rho, T, Ys, theta, d, F):
    A, a1, a2, a3, a4, a5 = params
    return (A * F * d**2) * (D/d)**(a1) * (S/F)**a2 * ((rho) * ((F)**2)/T)**a3 * (Ys/T)**a4 * theta**a5

# Define the residuals function for optimization
def residuals(params, data):
    D, S, rho, T, Ys, theta, MRR, d, F = data
    return np.sum((MRR - model(params, D, S, rho, T, Ys, theta, d, F))**2)
```

Figure 32: Excerpt from MRR python code

This code performs a nonlinear optimization to fit a model to experimental data.

The model describes material removal rate (MRR) as a function of various parameters, optimization is done using the Nelder-Mead method, and there's a mechanism to iteratively adjust parameters if the percentage difference between the experimental and calculated MRR exceeds a given threshold.

10.2.2 Test Design/Process

The test design and process included:

- Evaluation of a ø140mm round bar, then 110x110mm square bar.
- Sample thickness is kept to 3x blade thickness.
- Blade speed is kept constant at 1,33mm/sec.
- Blade Feed rate is increased using the knob position to indicate increase in feed.
- Recorded parameters: Feed rate, cutting speed, and time to cut.
- Objective: Assess the impact of varying blade thicknesses on cutting performance.

10.2.3 Equipment for the Test

Tests are performed on a Karmetal osa 350 x 450 CNC band saw. The machine constants are measured and inputted into the MRR function. The top angle is shown in figure 33 and guide distance is shown in figure 34. These are constants and will vary from saw to saw.

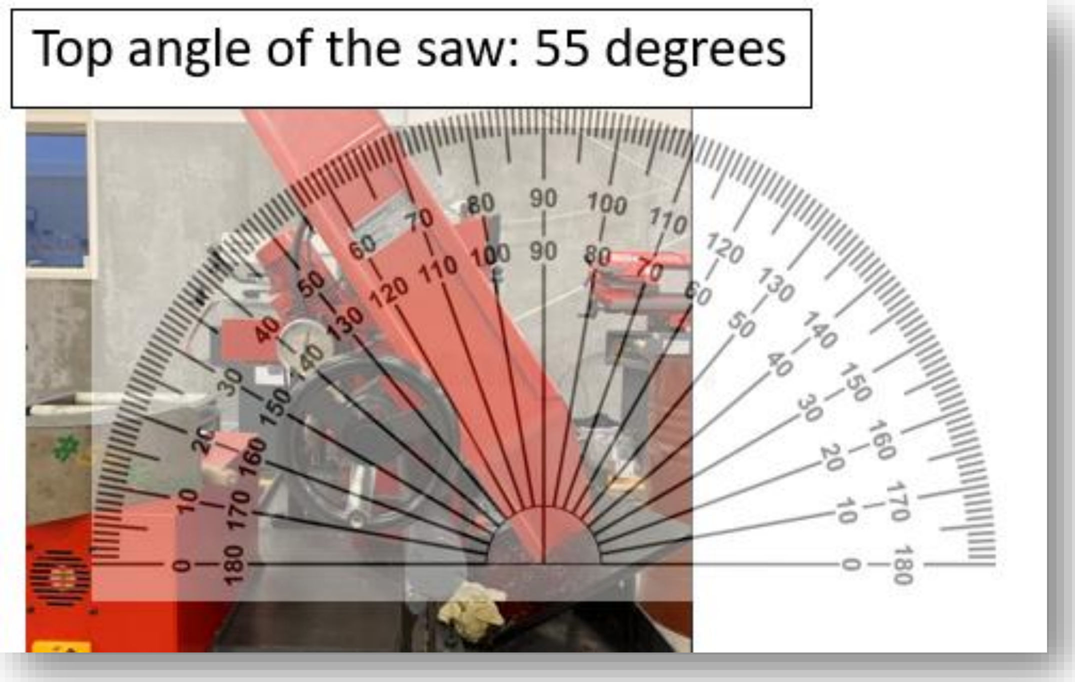


Figure 33: Estimation of top angle

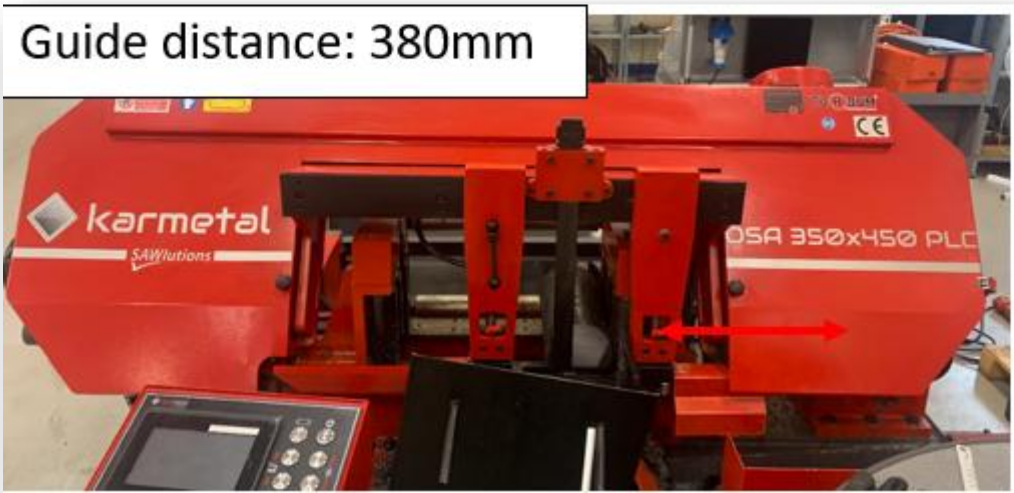


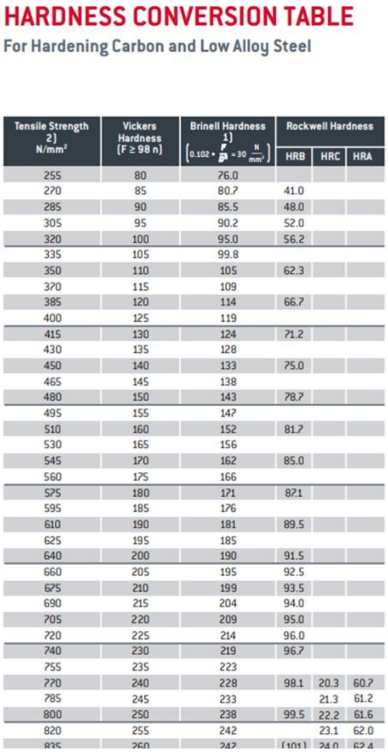
Figure 34: Estimation of guide distance

10.2.4 Material for the Test

To understand the material properties of the material cut, a hardness test is conducted, this hardness test is that converted to a tensile strength. This is then used as a constant in the MRR formula.

Table 3: Hardness of material

Round Bar	Square Bar
Hardness (HRB)	Hardness (HRB)
96,7	72,5
95,3	78,2
100,9	78,1
107,6	79,2
106,7	77,9
99,2	77,2
Mean	Mean
100,9601105	76,59932972



HARDNESS CONVERSION TABLE

For Hardening Carbon and Low Alloy Steel

Tensile Strength 2) N/mm²	Vickers Hardness (F ≥ 98 n)	Brinell Hardness 1) $\left(0.102 \cdot \frac{F}{D^2} = 30 \frac{N}{mm^2}\right)$	Rockwell Hardness		
			HRB	HRC	HRA
255	80	76.0			
270	85	80.7	41.0		
285	90	85.5	48.0		
305	95	90.2	52.0		
320	100	95.0	56.2		
335	105	99.8			
350	110	105	62.3		
370	115	109			
385	120	114	66.7		
400	125	119			
415	130	124	71.2		
430	135	128			
450	140	133	75.0		
465	145	138			
480	150	143	78.7		
495	155	147			
510	160	152	81.7		
530	165	156			
545	170	162	85.0		
560	175	166			
575	180	171	87.1		
595	185	176			
610	190	181	89.5		
625	195	185			
640	200	190	91.5		
660	205	195	92.5		
675	210	199	93.5		
690	215	204	94.0		
705	220	209	95.0		
720	225	214	96.0		
740	230	219	96.7		
755	235	223			
770	240	228	98.1	20.3	60.7
785	245	233		21.3	61.2
800	250	238	99.5	22.2	61.6
820	255	242		23.1	62.0
835	260	247	(101)	24.0	62.4

10.2.5 Conduction of the Test

During the conduction, the following are kept constant across all tests:

Table 4: Machine Constants

FACTOR	SYMBOL	UNIT	
Top arm angle	θ	Degree	55
Blade tension	T	N/mm2	110
Guide distance	D	mm	380
Teeth Per Inch	TPI		2,5
Blade speed	S	mm/sec	1,33

Using the constants measured in the previous sections, the tensile strength data presented in Figure 35 was input into the Python script. Table 5, labelled as 'Nelder-Mead Constant Results,' showcases the detailed outcomes of this analysis

Table 5: Nelder-Mead Constant results

Constants	
A	0,014258
a1	-0,42083
a2	0,891284
a3	0,39951
a4	-0,8246
a5	1,513294

Table 6: MRR for square bar

			Feed Knob Position					
FACTOR	SYMBOL	UNIT	2	3,5	4	5	5,5	6
Feed	F	mm/sec	0,296565	0,811497	1,18486	0,76303	1,436331	1,530201
Material density	p	gm/cm3	7,85	7,85	7,85	7,85	7,85	7,85
Job diameter	d	mm	110	110	110	110	110	110
Yield stress	Ys	N/mm2	300	300	300	300	300	300
Volume of cut mm3		mm3	15730	15730	15730	15730	15730	15730
Time to cut		min	6,1819	2,2592	1,5473	2,4027	1,2764	1,1981
MRR Experimental			2544,525	6962,642	10166,1	6546,802	12323,72	13129,12
MRR Calculated			3158,595	7362,818	10121,56	6991,304	11899,37	12549,88
Percentage Difference			80,55877	94,5649	100,44	93,64206	103,5662	104,6155
Chip Load		Fz	0,002224	0,006086	0,008886	0,005723	0,010772	0,011477

Table 7: MRR for round bar

			Feed Knob Position			
FACTOR	SYMBOL	UNIT	2	2	2,5	3,5
Feed	F	mm/sec	0,44414	0,458929	0,533004	0,949011
Material density	p	gm/cm3	7,85	7,85	7,85	7,85
Job diameter	d	mm	140	140	140	140
Yield stress	Ys	N/mm2	640	640	640	640
Time to cut		min	5,2536	5,0843	4,3777	2,4587
MRR Experimental			3809,186	3936,027	4571,337	8139,236
MRR Calculated			4112,173	4239,774	4874,918	8350,193
Percentage Difference			92,63195	92,83577	93,77258	97,47363
Chip Load		Fz	0,003331	0,003442	0,003998	0,007118

10.2.6 Test 2 - Conclusion

The hardness test is useful to estimate the yield strength, as visually the materials look similar but have vastly different material properties. Figures 36 and 37 show the areas allow the cut where the test are conducted.

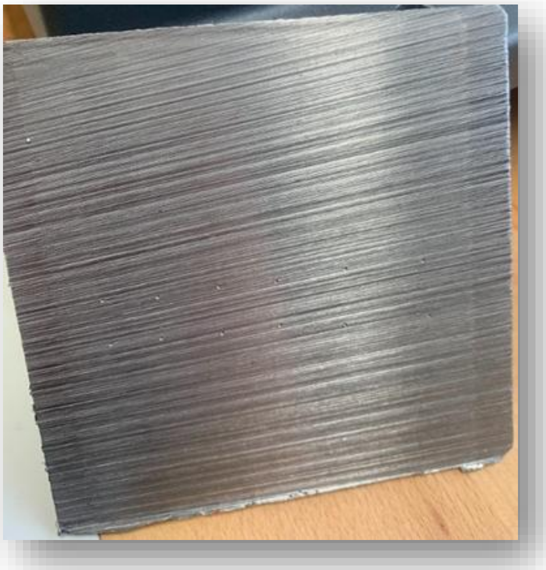


Figure 35: Hardness test of square bar

Figure 36: Hardness test of round bar

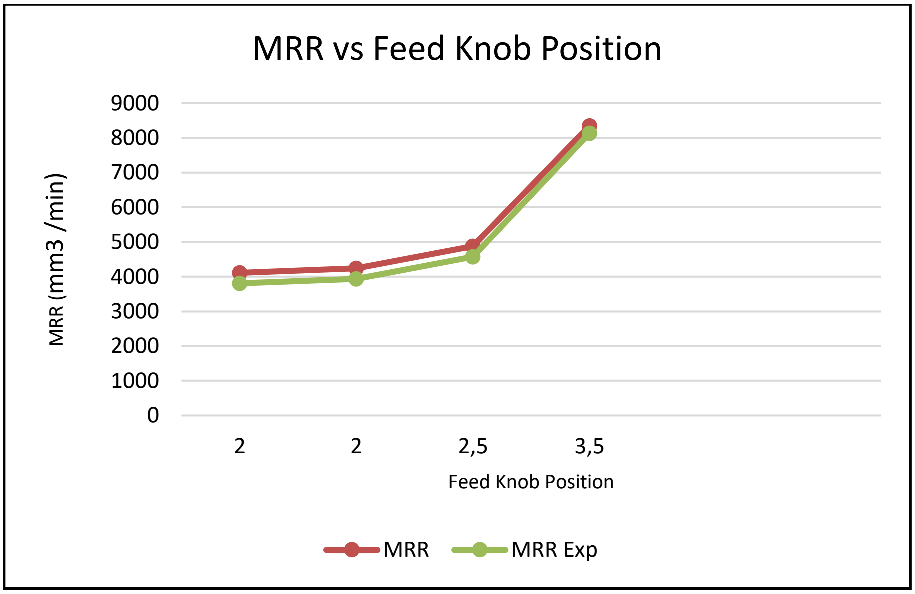


Figure 37: Graph of calculated MRR vs MRR Exp of square bar

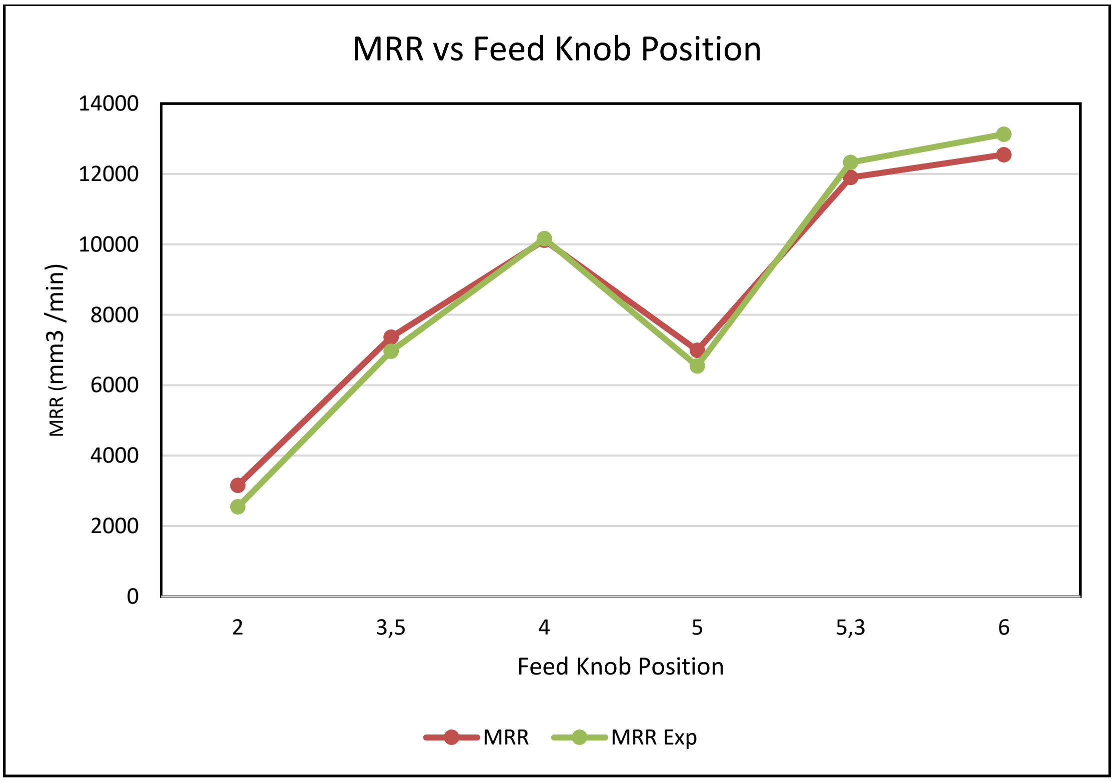


Figure 38: Graph of calculated MRR vs MRR Exp of round bar

The results from Test 2 indicate that deriving a theoretical Material Removal Rate (MRR) equation is feasible. When comparing the experimental data with the calculated values across both tests, the percentage difference is consistently within 10%.

10.3 Test 03

10.3.1 Introduction

In Test 3, we extend the work done in Test 2 by integrating the Nelder-Mead optimization constants and MRR calculation into a Python-based user interface. This test is designed to help operators efficiently identify optimal cutting parameters that maximize the Material Removal Rate (MRR). By leveraging the Python code developed in this test, operators can easily find a strong starting point for their machining processes, allowing for improved efficiency and performance on the shop floor. This test builds directly on the framework established in Test 2, enhancing it with practical tools for real-world application.

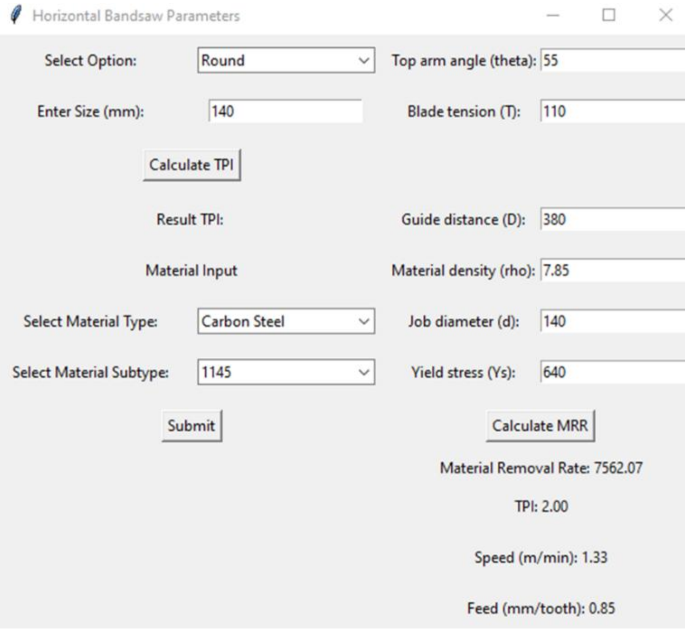
10.3.2 Test Design/Process

The test design and process included:

- Evaluation of a ø140mm round bar.
- Sample thickness is kept to 3x blade thickness
- Blade speed is kept constant at 1,33mm/sec.
- Blade Feed rate is increased using the knob position to indicate increase in feed.
- Recorded parameters: feed rate, cutting speed, and time to cut.
- Objective: Assess the UI.

10.3.3 Conduction of the Test

The calculator is designed to be simple, to give the user one place into enter the material they intend to cut as well as the machine constants. The output of Feed, Speed and TPI seek to give the operator an initial guess that can be worked on later. Figure 40 shows a screenshot of the UI.



Select Option: Round

Enter Size (mm): 140

Result TPI:

Select Material Type: Carbon Steel

Select Material Subtype: 1145

Top arm angle (theta): 55

Blade tension (T): 110

Guide distance (D): 380

Material density (rho): 7.85

Job diameter (d): 140

Yield stress (Ys): 640

Material Removal Rate: 7562.07

TPI: 2.00

Speed (m/min): 1.33

Feed (mm/tooth): 0.85

Figure 39: User interface of the calculator

Table 8: Calculator testing

FACTOR	SYMBOL	UNIT					
Feed Dial			3	3	3	3	3
Top arm angle	θ		55	55	55	55	55
Blade tension	T	N/mm2	110	110	110	110	110
Blade speed	S	mm/sec	1,333333	1,333333	1,333333	1,333333	1,333333
Feed	F	mm/sec	0,85	0,85	0,423888	0,85	0,85
Guide distance	D	mm	380	380	380	380	380
Material density	p	gm/cm3	7,85	7,85	7,85	7,85	7,85
Job diameter	d	mm	140	140	140	140	140
Yield stress	Ys	N/mm2	640	640	640	640	640
MRR Experimental			6210,452	5736,546	3635,494	6085,616	6375,666
MRR Calculated			6728,672	6728,672	3578,003	6728,672	6728,672
Percentage			92,29833	85,25524	101,6068	90,44305	94,7537
Time to cut			3,2223	3,4885	5,5046	3,2884	3,1388
Chip Load		Fz	0,004381	0,004047	0,002565	0,004293	0,004498

Test 3 demonstrates the feasibility of implementing a user interface (UI) to assist operators in the machining process. The code developed for this UI has shown a level of effectiveness comparable to that observed in Test 2, indicating that the interface is reliable and performs well under similar conditions.

This suggests that the UI can effectively support operations involving aluminium, thereby enhancing the overall efficiency and precision of the machining process. The consistent performance across different tests confirms the UI's potential as a valuable tool for operators working with various materials.

10.4 Test 04

10.4.1 Introduction

Test 4 focuses on validating the effectiveness of the Python-based user interface in the context of machining lead-free aluminium. Building on the successes of previous tests, this test specifically aims to assess how well the UI performs when used to optimize cutting parameters for lead-free aluminium, a material known for its unique machining characteristics. By doing so, Test 4 will determine the UI's versatility and reliability across different materials, ensuring that operators can confidently use the tool to achieve optimal Material Removal Rates (MRR) in diverse machining environments.

10.4.2 Test Design/Process

The test design and process included:

- Evaluation of a ø110mm round bar.
- Sample thickness is kept to 3x blade thickness.
- Blade speed is kept constant at 1,42mm/sec.
- Blade Feed rate is increased using the knob position to indicate increase in feed.
- Recorded parameters: feed rate, cutting speed, and time to cut.
- Objective: Assess the UI.

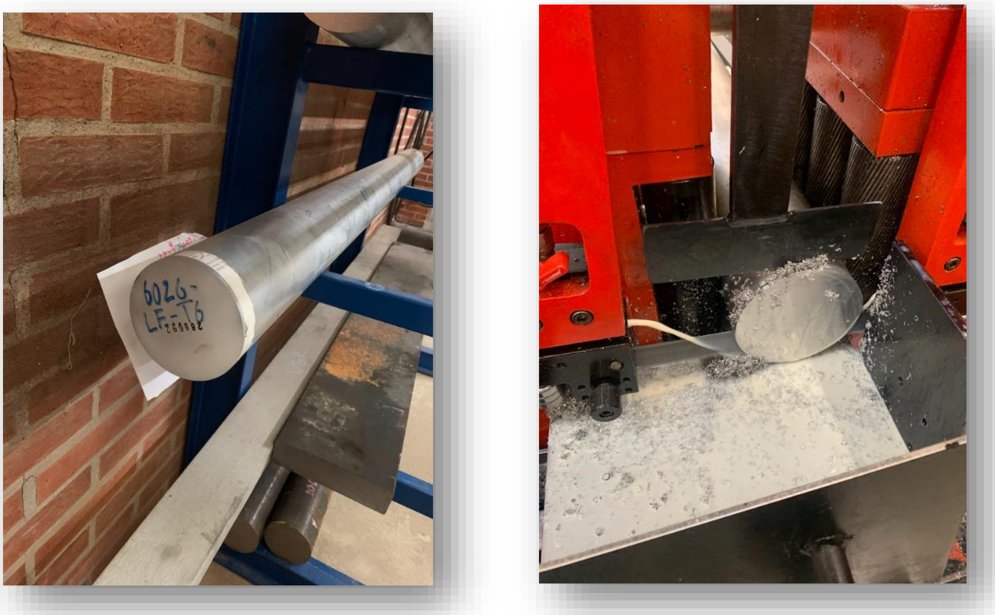


Figure 40: Test 4 - Parameter calculator test in lead free aluminium

10.4.3 Conduction of the Test

Table 9 shows the results of test 4, with the percentage difference between the experimental and calculated MRR being within a 10 percent difference.

Table 9: Test 4 - Results

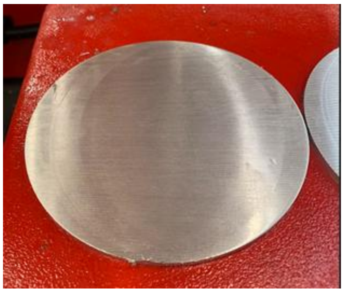
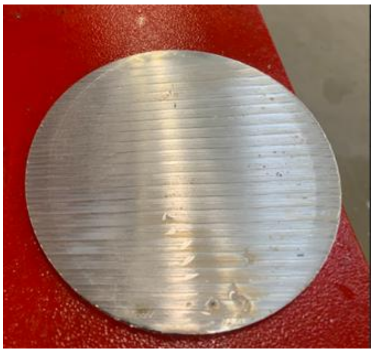
FACTOR	SYMBOL	UNIT				
Feed Dial			2	2	2,5	3,5
Top arm angle	θ		55	55	55	55
Blade tension	T	N/mm2	110	110	110	110
Blade speed	S	mm/sec	1,416667	1,416667	1,416667	1,416667
Feed	F	mm/sec	0,44414	0,458929	0,533004	0,949011
Guide distance	D	mm	380	380	380	380
Material density	p	gm/cm3	2,75	2,75	2,75	2,75
Job diameter	d	mm	120	120	120	120
Yield stress	Ys	N/mm2	300	300	300	300
MRR Experimental			3809,186	3936,027	4571,337	8139,236
MRR Calculated			4112,173	4239,774	4874,918	8350,193
Percentage			92,63195	92,83577	93,77258	97,47363
Time to cut		min	5,2536	5,0843	4,3777	2,4587
Chip Load		Fz	0,003331	0,003442	0,003998	0,007118

10.4.4 Test 4 - Conclusion

This test demonstrates that the user interface (UI) provides a high level of confidence in using the calculator for different materials.

Table 9 indicates an approximate 10% difference between the calculator's predictions and the experimental results, suggesting a reasonable level of accuracy. However, Table 10 below presents a visual assessment of the cuts, emphasizing the significant impact of feed rate adjustments on the cut quality. This highlights the importance of fine-tuning the feed rate to achieve the desired surface finish and accuracy.

Table 10: Surface finish of Test 4

Feed Position	Feed Position 2	Comments
2		• Very smooth, fine texture. • High-quality finish, minimal tool marks. • Light cutting, low feed rate, excellent for precision work.
2		• Very smooth, fine texture. • High-quality finish, minimal tool marks. • Light cutting, low feed rate, excellent for precision work.
2.5		• Slightly coarser texture • Some tool marks visible. • Moderate-quality finish, slight increase in roughness. • Moderate feed rate, balanced between finish and material removal.
3.5		• Noticeable tool marks, coarser texture. • Lower-quality finish, more pronounced roughness. • Higher feed rate, more aggressive cutting, suitable for faster material removal but with a rougher finish.

10.5 Test 05

10.5.1 Introduction:

Test 5 builds on the outcomes of Test 4, focusing on safely pushing the feed rates in lead-free aluminium machining to their upper limits. The primary objective of this test is to explore the maximum feasible feed rates while ensuring safe and stable operations. Additionally, the test will involve a detailed inspection of the chips formed at each feed rate, providing valuable insights into the machining process and the effects of varying feed rates on chip morphology. This continuation from Test 4 aims to refine the understanding of optimal cutting conditions and enhance material removal efficiency.

10.5.2 Test Design/Process

The test design and process included:

- Evaluation of a ø110mm round bar.
- Sample thickness is kept to 3x blade thickness.
- Blade speed is kept constant at 1,42mm/sec.
- Blade Feed rate is increased using the knob position to indicate increase in feed.
- Recorded parameters: feed rate, cutting speed, and time to cut.
- Objective: Assess the chips at increasing feed.

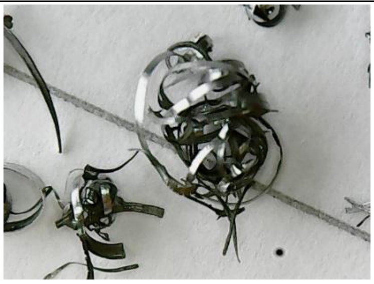
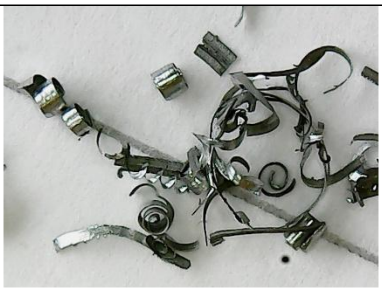
10.5.3 Conduction of the Test

Table 11: Test 05 - Results

FACTOR	SYMBOL	UNIT					
Feed Dial			2	3	4	5	7
Top arm angle	θ		55	55	55	55	55
Blade tension	T	N/mm2	110	110	110	110	110
Blade speed	S	mm/sec	1,416667	1,416667	1,416667	1,416667	1,416667
Feed	F	mm/sec	0,21164	0,617284	0,97561	1,459854	3,846154
Guide distance	D	mm	380	380	380	380	380
Material density	p	gm/cm3	2,75	2,75	2,75	2,75	2,75
Job diameter	d	mm	120	120	120	120	120
Yield stress	Ys	N/mm2	300	300	300	300	300
MRR Experimental			1555,836	4537,855	7172,024	10731,86	28274,33
MRR Calculated			1814,446	4794,449	7264,213	10473,04	25233,23
Percentage			85,74714	94,6481	98,73092	102,4713	112,052
Time to cut		min	9,45	3,24	2,05	1,37	0,52
Chip Load		Fz	0,001494	0,004357	0,006887	0,010305	0,027149

10.5.4 Test 5 - Conclusion

Table 12: Chip analysis of Test 5

Feed Position	Microscope Image of Chips	Chip Characteristics	Cutting Condition Indicators
2		Tight spiral chips are tightly curled, indicating low feed rate.	Light cutting, potentially smooth finish, and lower material removal rate.
3		Open spiral chips are slightly more open, but still curled.	Moderate feed rate, balanced between cutting efficiency and surface finish.
4		Small spirals and loops suggest an increase in feed rate.	Increased material removal, possible minor surface roughness.
5		Ribbon-like with minor tears chips are ribbon-like and show signs of tearing.	Chips begin to flatten out, indicating a higher feed rate. significant heat generation, possible tool wear.
7		Thick curled chips	Very aggressive cutting, high heat, potential for tool damage or failure.

Chip analysis in aluminium during metal band sawing presents unique challenges compared to steel. Unlike steel, where chips visibly change colour—blackening and turning blue due to the heat generated during cutting—aluminium chips do not exhibit such distinct visual cues.

This lack of colour change in aluminium makes it more difficult to assess cutting conditions and tool wear based solely on chip appearance. Therefore, careful observation of chip shape, size, and formation becomes crucial in aluminium machining. By analysing these factors, operators can still gain valuable insights into the cutting process, such as feed rate adequacy, heat generation, and potential tool wear. However, the subtle nature of aluminium chip characteristics requires a more nuanced approach and a deeper understanding of the material's behaviour under different cutting conditions.

10.6 Test 06

10.6.1 Introduction

In Test 6, we focus on evaluating the Material Removal Rate (MRR) performance of the PILOUS ARG-260 manual band saw. By using an MRR calculator, we aim to determine the optimal cutting parameters for different materials and analyse how these settings impact overall productivity.
Beyond the MRR, this test will also involve a detailed inspection of the chips produced during the cutting process. Chip formation provides valuable insights into the cutting conditions, such as blade sharpness, feed rate, and material characteristics. Proper chip analysis can help in adjusting the cutting parameters to improve efficiency and blade life.

10.6.2 Test Design/Process

The test design and process included:

- Evaluation of a ø120mm round bar.
- Sample thickness is kept to 3x blade thickness.
- Blade speed is kept constant at 0,67mm/sec.
- Blade Feed rate is increased using the knob position to indicate increase in feed.
- Recorded parameters: feed rate, cutting speed, and time to cut.
- Objective: Compare the Karmetal CNC results with this Pilous.

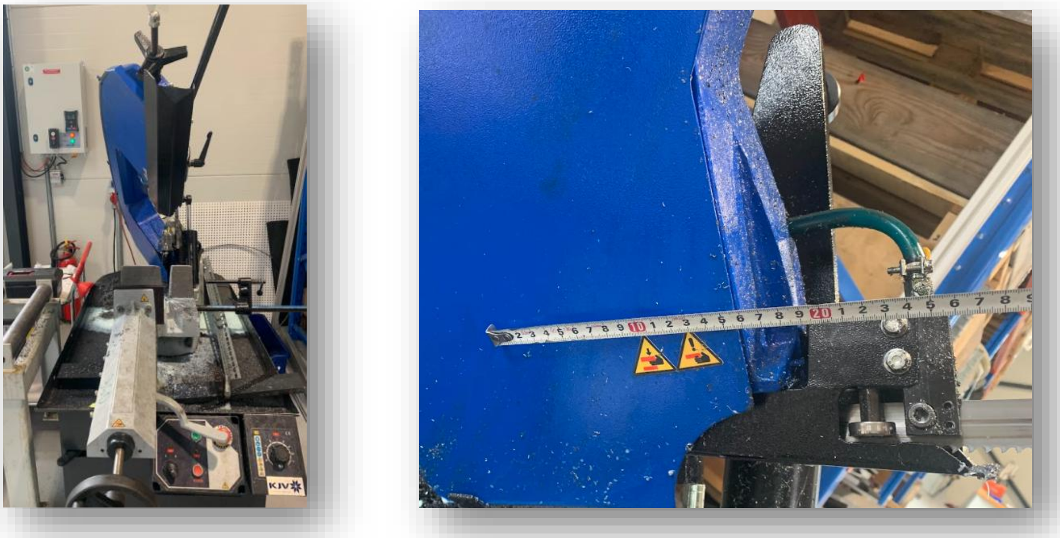


Figure 41: Pilous band saw arg-260

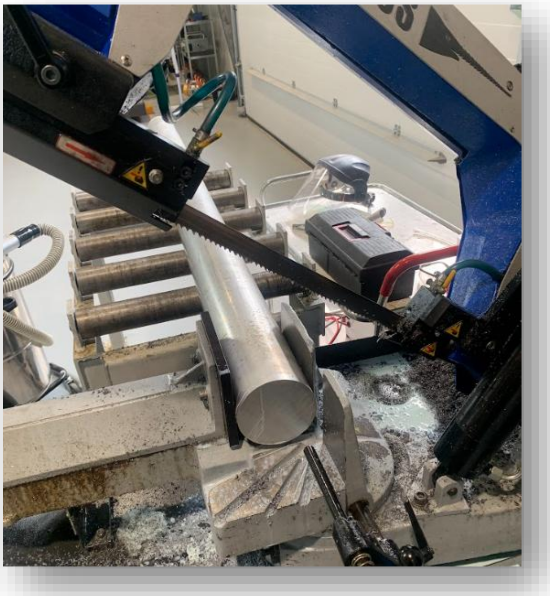


Figure 42: Test 06 setup

10.6.3 Conduction of the Test

FACTOR	SYMBOL	UNIT				
Feed Dial			2	3	2	3
Top arm angle	θ		55	55	55	55
Blade tension	T	N/mm2	140	140	140	140
Blade speed	S	mm/sec	0,583333	0,583333	1,166667	1,166667
Feed	F	mm/sec	0,351494	0,58309	0,2574	0,813008
Guide distance	D	mm	250	250	250	250
Material density	p	gm/cm3	2,75	2,75	2,75	2,75
Job diameter	d	mm	120	120	120	120
Yield stress	Ys	N/mm2	300	300	300	300
MRR Experimental			2583,945	4286,487	1892,233	5976,687
MRR Calculated			1723,167	2728,125	2408,829	6842,381
Percentage			149,9532	157,1221	78,55407	87,34805
Time to cut		min	5,69	3,43	7,77	2,46
Chip Load		Fz	0,003295	0,005466	0,002413	0,007622

10.6.4 Test 6 - Conclusion

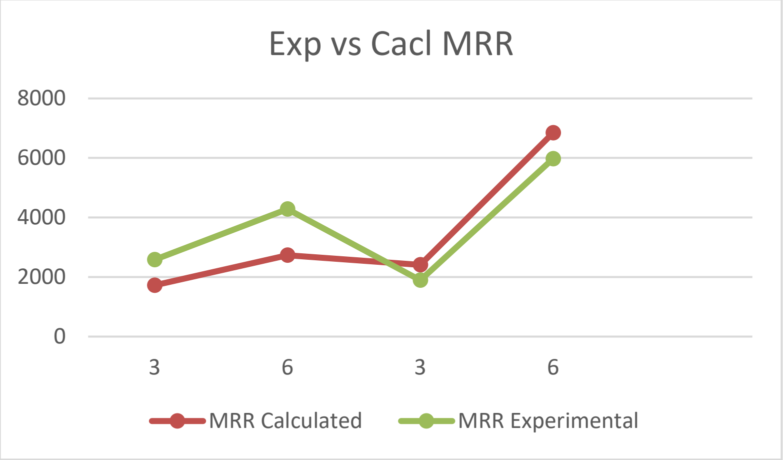


Figure 43: Graph of Experimental vs Calculated MRR

The comparison between the Karmetal CNC horizontal bandsaw and the more manual Plious saw reveals several key distinctions that impact the consistency and efficiency of material removal rates (MRR):

Workpiece Handling and Repeatability

- **Karmetal CNC**: The vice mechanism of the Karmetal allows for precise positioning of the workpiece, accounting for blade kerf (the material width removed by the saw blade). This leads to significantly more repeatable cuts in terms of width. The ability to control the position of the workpiece mechanically with precision greatly reduces variability in the dimensions of the cut material.
- **Plious Saw**: In contrast, the more manual approach of the Plious saw, which lacks this advanced positioning feature, introduces more human error and inconsistency. Achieving cuts of the exact same width repeatedly is much more challenging, which could explain the deviation in the consistency of MRR when compared to the Karmetal CNC.

Blade Speed Control

- **Karmetal CNC**: The Karmetal's CNC system allows for variable blade speeds that can be adjusted for different material types and thicknesses. This flexibility ensures that the saw operates at an optimal speed for both efficiency and material integrity.
- **Plious Saw**: On the other hand, the Plious saw offers only two blade speeds, limiting its ability to adapt to different cutting conditions. This reduced flexibility in blade speed may lead to inefficient cutting, either by operating too slowly for the material or causing excess friction and heat at faster speeds. This variability impacts the calculation of MRR as it introduces additional uncertainty into the cutting process.

Mean Difference in MRR

The mean difference in MRR between the experimental data and the calculated data is significant:

- **Karmetal CNC**: The calculated MRR was more in line with expectations, showing only a 4% difference between experimental and calculated values. This relatively low percentage suggests that the constants used in the MRR formula are fairly accurate for the CNC machine, likely due to its precision and repeatability.
- **Plious Saw**: By contrast, the Plious saw exhibited a 12% difference between the experimental and calculated MRR. This larger deviation suggests that the manual saw's operational inconsistencies, such as those caused by less precise workpiece handling and limited speed settings, are significant enough to affect the MRR calculations. The variation in cutting conditions introduced by the Plious saw's limitations likely contributes to this disparity.

Adjusting MRR Constants

To achieve more accurate MRR calculations, especially when comparing cuts made with both the Karmetal and Plious saws, it would be necessary to integrate the data from both machines into the constant calculation. The greater variability seen with the Plious saw's MRR (12% vs. 4%) suggests that the constants used in the equation need to be adjusted to account for machine type and operational variability.

Recommendations for Future Analysis

- **Account for machine type in MRR calculations**: Incorporating separate constant adjustments for each machine, based on their unique operational capabilities, may help reduce the disparity between calculated and experimental MRR.
- **Further experiments**: More cuts using both machines under a variety of conditions could provide a broader dataset for refining the constants and improving calculation accuracy.
- **Additional variables**: Factors such as operator skill level (for the Plious saw) and material properties should also be considered in future evaluations to ensure a more comprehensive understanding of the differences in MRR between the machines.

10.7 Inspection of Wear

10.7.1 Introduction

An area of interest is an inspection of the wear on the blade under various conditions.

One scenario inspected is how the saw is used to remove prints from a metal baseplate. Blade tip breakage was observed. To look deeper into the damage, a microscope is employed at various magnification levels to inspect the blade's condition, focusing on the impact of wear on the cutting edges and overall blade performance. This inspection process is guided by the band saw manufacturer's recommendations, providing a systematic approach to evaluating blade wear and its potential effects on cutting efficiency and safety. Through detailed microscopic analysis, insights into the blade's longevity and maintenance needs can be obtained, ensuring optimal performance throughout the WAAM project.

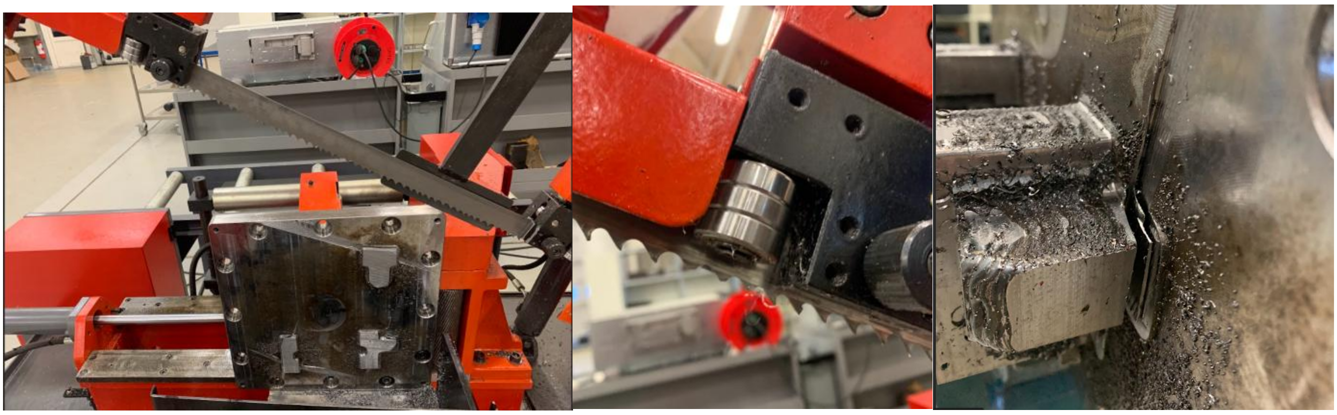
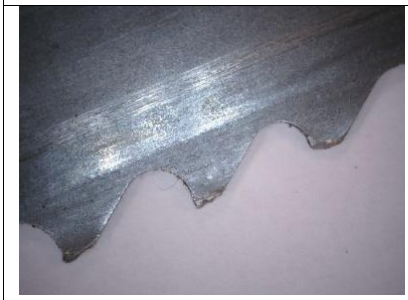
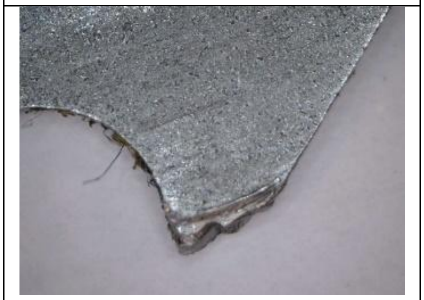
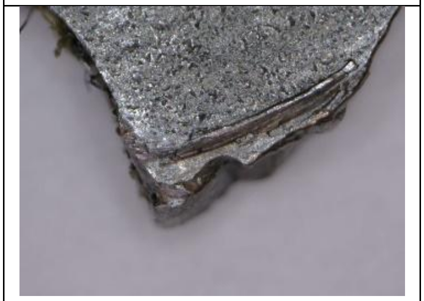
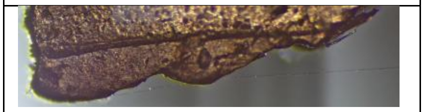


Figure 44: Bandsawing of an irregular workpiece

This inspection process is guided by the band saw manufacturer's recommendations, providing a systematic approach to evaluating blade wear and its potential effects on cutting efficiency and safety. Through detailed microscopic analysis, insights into the blade's longevity and maintenance needs can be obtained, ensuring optimal performance throughout the WAAM project.

Table 13: Microscope images of bandsaw wear

Tooth	Comments
	The zoomed images show the damage to the tooth. The overfeeding impacts chip the tooth and create a jagged edge.
	
	
	

The microscope analysis of the blade tip reveals significant wear and deformation, which are indicative of the challenges faced when cutting irregular workpieces. The observed damage, including chipped or dulled teeth, suggests that the uneven geometry of the workpiece places excessive stress on specific points of the blade, leading to concentrated wear and potential micro-cracks.

Over time, these stresses can accumulate, increasing the risk of blade breakage. The irregular contours of the workpiece may cause inconsistent contact with the blade, resulting in uneven force distribution and heightened susceptibility to damage. This analysis underscores the importance of using appropriate cutting techniques and equipment when working with irregular materials to minimize the risk of blade failure and ensure operational safety and efficiency.

11. Straightness of Cut

11.1 Introduction

Straightness of cut may be used to evaluate how reduce material waste and reduce the need for more than necessary processes after sawing. As such straightness of cut of test 04 and test 05 are measured using a TESA MICRO-HITE 3D CMM surveyor.

11.1.1 Test Design/Process

The evaluation process included:

- Evaluation of a cut specimens from test 04 and 05.
- The straightness is measured down the centre of the cut specimens, following the path of the blade down the material.

Figure 45: Straightness of cut measurement

11.1.2 Results

Table 14: Table results of straightness test

	Feed Knob Position	Flatness	Straightness 22pts	Straightness 63pts
Test 4	2	0,075	0,4983	0,5049
	2	0,0359	0,1388	0,1666
	2,5	0,0874	0,3169	0,3441
	3	0,3364	0,9762	0,9026
Test 5	2	0,24	0,3138	0,3255
	3	0,34	0,9515	0,758
	4	0,32	0,7136	0,7602
	5	0,24	0,67	0,7996
	7	0,27	0,84	1,0906

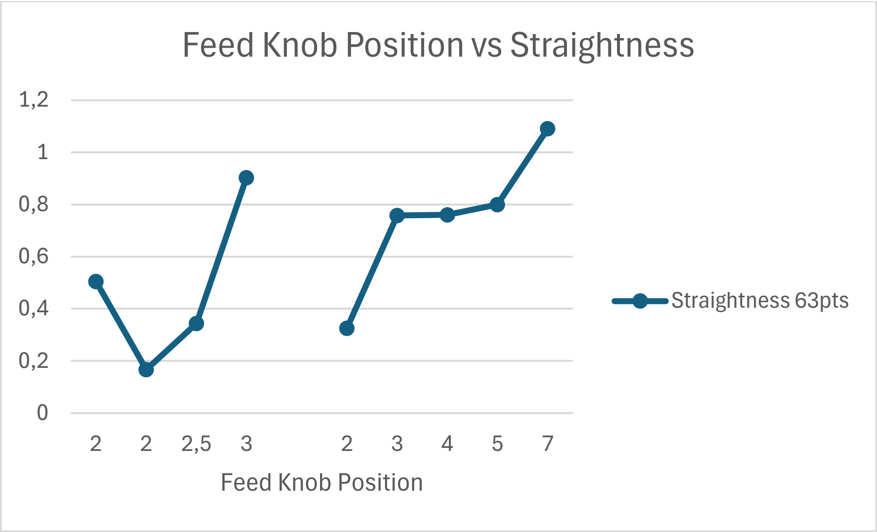


Figure 46: Graph of straightness test results

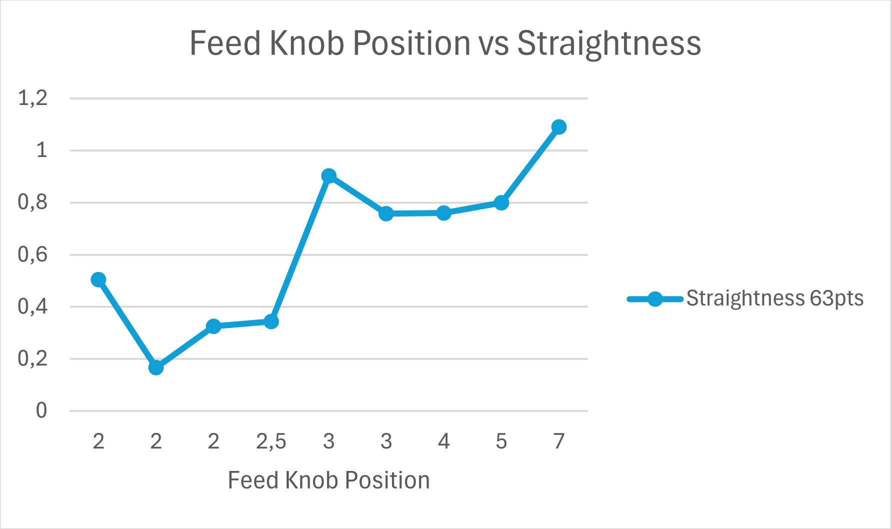


Figure 47: Combined straightness test results

11.1.3 Conclusion

The CMM provides a straightness value, representing the maximum deviation of the surface from perfect straightness.

- As the feed knob position increases, the straightness value generally increases. The data shows a clear upward trend from position 2 to 7, indicating that the cut becomes less straight at higher feed rates.

In the context of manufacturing, higher straightness values typically indicate greater deviations from a perfectly straight line. This suggests that:

- At lower feed rates (positions 2 to 3), the cut is more accurate or "straighter," meaning less deviation occurs, and less material would need to be removed for finishing.
- As the feed rate increases (positions 4 to 7), the straightness value worsens, meaning more material would need to be removed during a secondary operation to achieve the required surface quality or dimensional accuracy.

12. Discussion

In our investigation, we made several key adjustments to align with the application’s requirements and the current market understanding of sawing techniques. The market surveys did not lead to a specific problem to solve, rather an overall feeling that parameter optimisation is not readily done in industry. This lack of specificity led us to modify our approach in a way that tested theoretical frameworks rather than solving an immediate operational issue

12.1 Application Modifications

12.1.1 Adjustment to Test Conditions

Due to the general nature of the problem—without a distinct challenge to solve—we derived a testing methodology based on theoretical performance metrics. The absence of specific real-world issues required us to shift focus to standardizing test variables, such as material type, cutting speed, chip load, and straightness. These factors reflect common concerns in industrial applications, ensuring that our results would still hold value for various market scenarios, even if they did not directly solve an immediate problem.

12.1.2 Market-Oriented Testing

The design of the tests was driven by market understanding, meaning that instead of exploring niche or isolated issues, we chose two examples that represented common industrial concerns. We aimed to test saw blades commonly found in the market a bi-metal variable-pitch blades under typical usage conditions in the metalworking industry. The materials tested were two steel dimensions and the lead-free aluminium.

12.1.3 Why These Adjustments Were Necessary

The theoretical approach allowed us to simulate various cutting conditions and draw conclusions on the performance of different parameters. This ensured that our research could still provide valuable insights, even without a precise practical application. Theoretical testing also offers flexibility, allowing conclusions to be extrapolated across multiple potential problems, which is useful when market conditions vary widely between industries.

12.1.4 How the Changes Were Implemented

To accommodate the theoretical focus of the application, we devised a structured experimental setup that tested multiple sawing parameters under controlled conditions.

The parameter investigation was interesting, the effect of the adjustment of feed rate on chip size and straightness are crucial when sawing. This showed that providing a truly optimised cut is nuanced as one can increase MRR at the detriment of these other factors.

By adjusting our methodology in this manner, we ensured that even without solving a specific issue, the tests would still provide actionable insights for market-relevant applications. The findings would help industries choose the appropriate blade types for various scenarios, improving their cutting efficiency and reducing operational costs over time.

13. Conclusion

13.1.1 Test Results

The tests conducted on two different band saw machines using two distinct blades, under varying machine parameters, demonstrate that cut quality is strongly influenced by these factors. It is evident that the blade thickness plays a significant role, as specimens with a thickness less than three times the blade's thickness exhibit material bowing, leading to inaccurate cuts and increased post-processing.

Additionally, while an experimental Material Removal Rate (MRR) can be computed, the constants in the MRR equation vary depending on the geometry of the cut and the specific machine characteristics. This implies that standardizing the MRR formula across machines may be difficult due to these machine-specific dependencies. However, even with this variability, a calculator that provides operators with recommendations on blade TPI (teeth per inch), feed rates, and speeds based on the material being cut can still prove invaluable. It can serve as a guideline to improve overall efficiency and cut quality in a range of cutting scenarios, particularly for operators who lack experience or specialized training.

13.1.2 Success Criteria

The findings suggest that there is no standardized set of cutting parameters specifically tailored to different materials for band sawing operations. This is likely due to the perception that sawing is a rough-cutting process, which traditionally has not been seen as requiring in-depth optimization. However, this mindset has limited the potential for significant improvements in cut quality, efficiency, and material waste reduction.

The project's success lies in its ability to raise awareness within the industry about the untapped potential for improving sawing processes through optimization. By introducing more targeted tools (such as the proposed calculator), the project can help foster an interest in the topic and potentially inspire vast improvements in how stock materials are processed. These improvements could include reduced material waste, improved cut accuracy, and increased operational efficiency.

13.1.3 Next Steps

To continue improving the band sawing process, operators need more resources—both in the form of data and tools. The calculator developed during this project represents one such resource, providing operators with the ability to select the appropriate blade type and machine parameters based on the material to be cut. This tool could greatly benefit operators by reducing trial-and-error, thus saving time and materials.

Additionally, providing training programs to operators, such as a half-day course, could be a highly effective way to disseminate this knowledge. The training would focus on teaching operators how to use tools like the calculator, understand the importance of feed and speed optimization, and improve overall cut quality.

Further testing should be aimed at addressing specific industrial challenges, particularly those faced by individual companies or sectors that deal with non-traditional materials, such as composites. These materials are not typically included in supplier-provided speed and feed charts, making it crucial to conduct experimental tests to determine optimal cutting parameters and blade recommendations for these materials. This would open new areas for research and development in band sawing operations, helping the industry evolve to meet the demands of cutting-edge materials.

Dissemination

This project is presented on the DAMRC website here: https://www.damrc.dk/optimale-procesparametre-for-baandsave/.

On the 28 November 2023 DAMRC held a technology seminar to partners and the public to display and discuss the ongoing research projects in the company.

Appendix

8.13 P1001-4-12 Optimal band saw an interview with JP Group.

This interview is based on a loose talk with the quality and the saw operator to hear more about have they are using the saws they have.
Date: Thursday 07/09-2023 13:30-15:00
Participant:
DAMRC: RMP, SIS.
JP Group: Jesper Knudsen (Produktions chef)

JP group have multiple saws and saw around 90.000-120.000 tubes a year they then use for their production of spare parts to old retro cars like WW bubble and Porsche. All tubes gets deburred after cutting.
They often have 3-4 people service the saws at once most of the time.
They have multiple saws, but their most used ones are circular saws since they are cutting thin tubes in diameter ranging from 20-200mm in diameter. This makes sense as they are fast cutters. Their saw is an old model from 1975 the second most used one is from around the 1980. They do at this time not have a Computer controlled saw.
They have a senior employee that oversees the sawing processes who has been in the company for a very long time, other than that they often employ non-educated young people to operate the saws and keep the process going supervised by the senior employee. These people do sometimes not change the sawblade on the right time and thereby make a lot of burrs, which then take more time to deburred afterwords.
The sawblades are changed, and re grinded at a low cost and they don’t buy new ones that often. The TPI is around 4-6 and they change them if they change from normal steel to stainless steel. They applied cutting flued as a mix of water and oil. With around 10% oil. They apply around a bucket of water a week, but there is no registration of have often they add the bucket of water, or any measurement of the olie/water mix.
They change the sawblades when they start to make a bad cut, but they don’t register when they change it or have often, they resharpen the sawblades.
All in all, there is no continuous quality control on the saws or on the parts coming from, and there is no registrations of quality faults or ongoing maintenance of the saws.

List of Figures

9. References

Brüggemann, D. K. (2022). Fundamental Analysis of a Circular Metal Sawing Process. In: Gapiński, B., Ciszak, O., Ivanov, V. (eds).

detroitbandsaw. (2024, 09 10). *detroitbandsaw*. Retrieved from https://www.detroitbandsaw.com/: https://www.detroitbandsaw.com/resource-library-faqs/band-saw-blades/

Diebold, J. &. (2021). CUTTING DEVIATIONS IN BANDSAWING OF CYLINDRICAL METAL PARTS.

Fu, J. L. (2023). Overview of the development of wear in bi-metal band saw blades. *Int J Adv Manuf Technol 128, 4735–4748*.

handymansworld. (2024, 09 02). *handymansworld.* Retrieved from handymansworld.net: https://handymansworld.net/types-of-bandsaw-blades/

Lenox. (2024, September 02). Retrieved from Sawcalc.com: https://www.sawcalc.com/images/lenox-guide-to-band-sawing.pdf

Mewada, B. G. (2018). Prediction model development for material removal rate in band sawing using dimensional analysis approach. *International Journal of Machining and Machinability of Materials*, 165.

Roentgen. (2024, September 02). Retrieved from www.roentgen-saw.com: https://www.roentgen-saw.com/images/pdf/technical_guide.pdf

Sfckoenig. (2024, 09 10). *sfckoenig*. Retrieved from www.sfckoenig.com: https://www.sfckoenig.com/wp-content/uploads/2018/08/hardness-conversion-table_EN.pdf

Sucksdorff, P. (2023). Effect of sawing parameters on sawblade lifespan. *Lappeenranta–Lahti University of Technology LUT*, 72.
