

# Analysis of Tool Failure in Stainless Steel Pipe Notching Using Bi-Metal Hole Saw under Manual Operation

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**Abstract** - The notching process of stainless steel pipes is widely applied in fabrication industries, particularly for structural joint preparation. However, machining stainless steel presents inherent challenges due to its low thermal conductivity, high toughness, and work hardening characteristics. This study investigates tool failure in a bi-metal hole saw used under manual machining conditions based on real industrial observations. The research adopts an observational approach without controlled parameter variation, reflecting actual shop-floor conditions. The results indicate that tool degradation is strongly influenced by thermal accumulation, unstable manual feeding, and insufficient cooling conditions. The dominant wear mechanisms include abrasive wear, adhesive wear, and thermal degradation. Furthermore, the use of an alternative method such as an angle grinder improves productivity but reduces dimensional accuracy. This study highlights the importance of thermal management and process stability in improving machining performance in manual systems and provides practical insights applicable to small- and medium-scale industries.

**Keywords:** Cutting tool wear, Stainless steel machining, Manual machining process, Thermal effects in machining, Process stability.

## I. INTRODUCTION

Pipe notching plays an important role in the manufacturing industry, particularly in tubular structure fabrication. This process ensures geometric compatibility between joining components, thereby maintaining assembly quality. The development of machining technology has led to the widespread adoption of CNC-based automated systems. However, many small and medium-scale industries still rely on manual methods due to their operational flexibility, relatively low investment cost, and ease of on-site implementation.

Manual machining systems have limitations in process parameter control. Operators are unable to precisely maintain cutting speed, feeding force, and cooling distribution. This

condition leads to high process variability, which contributes to reduced product quality and an accelerated rate of cutting tool wear.

Stainless steel is classified as a difficult-to-machine material. It has low thermal conductivity, which prevents efficient heat dissipation from the cutting zone. As a result, heat accumulates at the cutting interface, significantly increasing local temperature. Stainless steel also exhibits work hardening during plastic deformation, which increases material hardness and raises resistance to the cutting process.

Previous studies have shown that cutting tool wear in stainless steel machining is strongly influenced by thermal and adhesive effects. Inadequate cooling conditions and unstable process parameters contribute to the acceleration of wear mechanisms [1,2]. Wu et al. [3] further demonstrated that increased temperature in the cutting zone has a direct relationship with the acceleration of tool wear rate.

Most existing studies are conducted using CNC machines under controlled process parameters. Such experimental environments produce stable and reproducible cutting conditions. However, these conditions differ significantly from industrial practice, where manual systems are still widely used. This discrepancy creates a gap between academic findings and real-world manufacturing conditions.

Manual machining systems are highly influenced by human factors. Operators introduce variations in feeding force, working position, and spindle speed during operation. These variations make the machining process non-deterministic in nature. Tatar and Svenningsson [4] classify such conditions as a stochastic machining system characterized by high parameter variability.

Cooling systems in manual processes are often applied intermittently and without standardization. Operators apply cutting fluid inconsistently, resulting in non-uniform temperature distribution. This condition contributes to accelerated tool degradation. Previous studies have shown that effective cooling strategies such as Minimum Quantity

Lubrication (MQL) can improve tool life and machining quality.

This study aims to analyze cutting tool failure in stainless steel pipe notching using a bi-metal hole saw under manual machining conditions. The study identifies wear mechanisms, examines the role of thermal effects, and evaluates the influence of process instability on tool life.

This research bridges the gap between laboratory-based studies and real industrial conditions through direct observation of manual machining systems. This approach provides an applied understanding of cutting tool failure mechanisms under non-ideal and uncontrolled operating conditions.

## II. METHODOLOGY

This study employed a descriptive approach based on direct observation of machining processes in an industrial environment. The approach aims to understand cutting tool failure phenomena under real operating conditions without parameter intervention.

The pipe notching process was carried out using a manual pipe notching machine driven by a Hitachi DUT-13 hand drill, a 600 W heavy-duty electric drill designed for metalworking applications. The tool features a chuck capacity of 1.5–13 mm, a no-load speed of up to 1,800 RPM, and a weight of approximately 2.2 kg. The cutting tool used was a bi-metal hole saw with a diameter of 33 mm. The workpiece material was a stainless steel pipe with a diameter of 1 inch and a wall thickness of 3.35 mm. The equipment and materials used in this study are shown in Figures 1 to 3.



Figure 1: Stainless steel pipe material



Figure 2: Bi-metal hole saw cutting tool (a) and Hitachi DUT-13 hand drill as the notching machine drive unit (b)



Figure 3: Pipe notching machine (a) and manual pipe notching machine setup (b)

The machining process exhibits several key characteristics. The operator performs manual feeding throughout the operation. The cooling system is applied intermittently and is not continuous. Spindle speed cannot be precisely controlled during the cutting process.

This study does not involve experimental variation of process parameters. Instead, it focuses on interpreting phenomena occurring under actual industrial conditions. The analysis is based on relevant machining theories, particularly cutting tool wear mechanisms and thermal effects.

The observational approach provides a contextual understanding of real industrial process conditions. The findings can be directly applied in practice without requiring significant adaptation to field conditions.

## III. RESULTS AND DISCUSSIONS

### 3.1 General Observation of Cutting Tool Failure

Field observations indicate that the cutting tool experienced a progressive degradation in performance during the notching process. In the initial stage, the cutting operation proceeded stably and produced the intended geometry. The cutting tool maintained good sharpness, and the cutting force remained relatively low.

As the duration of use increased, the cutting resistance also increased. The operator reported a higher load during operation, indicating a decline in tool performance. In the subsequent stage, a significant reduction in cutting edge sharpness was observed. Cutting time increased, and product quality gradually deteriorated. Geometric deviations began to appear in the notched results. The operator applied additional force to maintain the cutting process, which in turn accelerated tool degradation. Visual inspection of the used tool revealed noticeable changes in tooth geometry. These changes indicate the presence of combined and complex wear mechanisms. The observed changes in the hole saw are shown in Figure 4, while defective products caused by tool wear are presented in Figure 5.

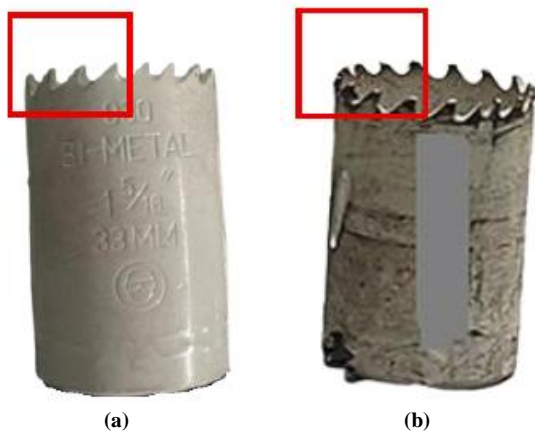


Figure 4: New hole saw with sharp cutting teeth (a) and used hole saw showing wear on the cutting teeth (b)

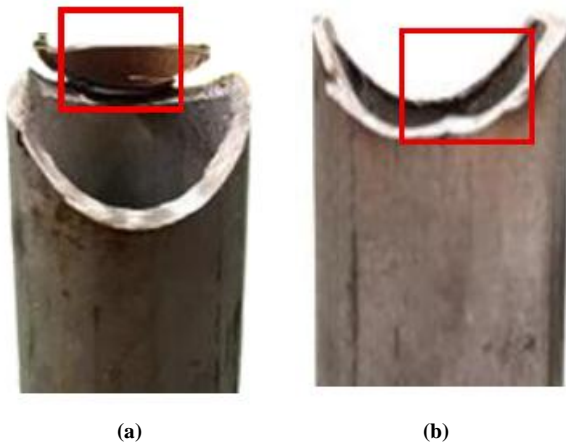


Figure 5: Incompletely cut product (a) and product with out-of-standard profile (b)

### 3.2 Analysis of Wear Mechanisms

The theoretical analysis indicates that cutting tool wear involves three primary mechanisms, namely abrasive wear, adhesive wear, and thermal degradation. These mechanisms act simultaneously during the cutting process, contributing collectively to tool deterioration. The combined wear mechanisms are illustrated in Figure 6, while Figure 7 presents the resulting consequences on the product due to tool wear. Furthermore, Figure 8 provides a conceptual illustration of how these wear mechanisms may develop during operation.

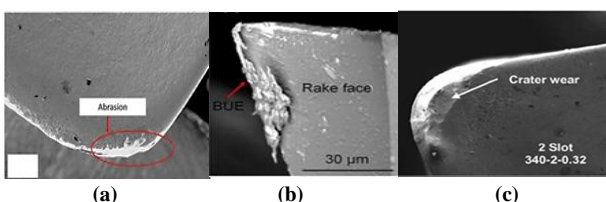


Figure 6: Tool wear mechanisms including abrasive wear (a), adhesive wear (b), and thermal degradation(c), adapted from the literature [5–7]

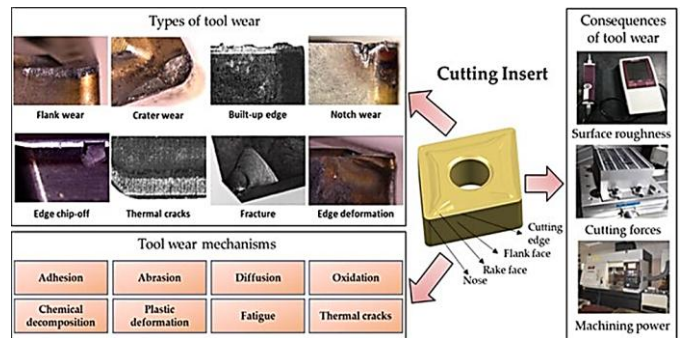


Figure 7: Types of tool wear and wear mechanisms [8]

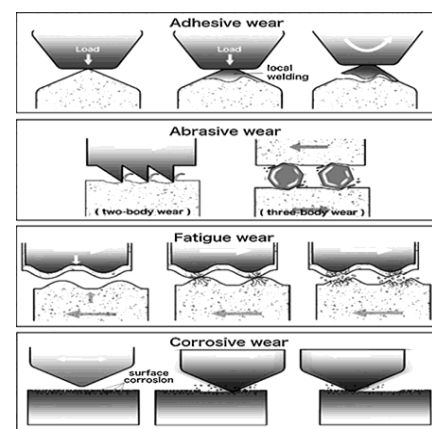


Figure 8: Conceptual illustration of cutting tool wear mechanisms: abrasive wear, adhesive wear, and thermal degradation [9]

Abrasive wear occurs due to the interaction between the cutting tool surface and hard particles from the stainless steel material. The work hardening phenomenon increases the surface hardness of the material. This hardened surface acts as an abrasive agent that progressively wears the cutting tool.

Adhesive wear occurs as a result of direct contact between the cutting tool and the workpiece material at elevated temperatures. Stainless steel adheres to the tool surface, leading to the formation of a built-up edge. This structure is unstable and interferes with the cutting process.

Thermal degradation is identified as the most dominant mechanism in this process. High temperatures reduce the hardness of the cutting tool material, causing a loss of its ability to maintain sharpness. The thermal degradation mechanism is associated with elevated cutting temperatures that lead to reduced tool hardness, surface oxidation, and the potential formation of micro-cracks due to thermal loading.

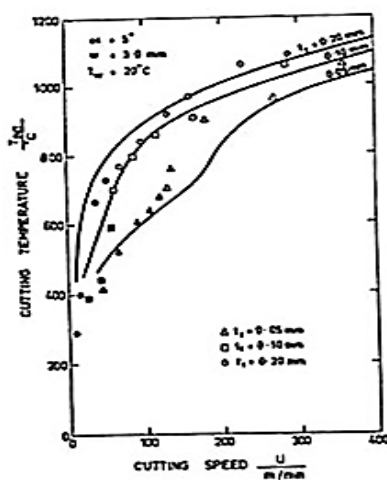
### 3.3 Dominance of Thermal Effects

Thermal effects play a major role in determining the service life of the cutting tool. Stainless steel has low thermal conductivity, which causes the heat generated during cutting

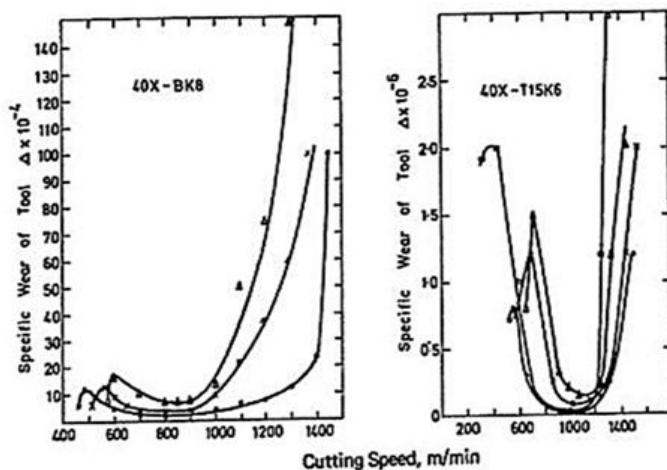
to accumulate in the cutting zone, leading to a significant increase in temperature.

High temperatures induce changes in the mechanical properties of the cutting tool material. The hardness of the tool decreases, and its resistance to deformation is reduced. This condition accelerates the wear rate of the cutting tool.

Cutting temperature arises from the contact between the tool and the workpiece during the machining process. It is influenced by machining conditions such as cutting speed, feed rate, and depth of cut.



(a)



(b)

Figure 9: The example of the relationship between cutting speed, cutting temperature (a) and specific wear of tool (b) [10, 11]

The demand for higher productivity and excellent surface integrity of machined components leads to concentrated heat generation in the cutting zone, which is detrimental to the effective service life of the cutting tool. Although cutting temperature generally increases proportionally with cutting speed, specific tool wear behavior indicates the existence of an

optimum low cutting temperature between mechanically induced wear and thermally induced wear, as illustrated in Figure 9.

The increased localized pressure on the cutting tool due to higher cutting speeds requires adequate cooling to maintain the tool temperature below its maximum operating range, typically 800–1200 °C for hard tool materials such as high-speed steel (HSS) or cemented carbide (WC) [11–13].

The relationship between temperature and tool wear exhibits a non-linear behavior, where the wear rate increases significantly once the temperature exceeds a certain threshold [14]. This condition indicates the existence of a thermal threshold beyond which tool degradation accelerates.

Intermittent cooling further exacerbates this condition. The non-uniform temperature distribution accelerates cutting tool failure and reduces tool life [1,14,15].

### 3.4 Effect of Manual Feeding System

The manual feeding system induces fluctuations in cutting force during the machining process [14,16]. Since the operator cannot maintain a perfectly constant feed rate and pressure, these variations lead to unstable cutting conditions.

The analysis of cutting force fluctuation problems in manual systems can be described as follows:

#### a) Root Cause (Human Factor)

Human operators have physical and cognitive limitations in maintaining a perfectly constant feed rate and pressure over an extended period [16].

#### b) Process Impact (Instability)

1. **Non-uniform cutting force:** Variations in cutting force cause fluctuating tool loads during operation.
2. **Vibration (chatter):** Unstable cutting conditions often trigger vibrations, which deteriorate the surface quality of the workpiece [14,16].
3. **Tool/workpiece deflection:** Excessive force may cause bending of the tool or workpiece, resulting in dimensional inaccuracy [14,16].

#### c) Output Impact (Quality)

1. **Non-uniform surface roughness:** The final machined surface finish becomes poor and inconsistent [17,18].
2. **Reduced tool life:** Force fluctuations introduce shock loading on the cutting tool, accelerating wear or causing chipping [15,17,18].

In summary, the conceptual illustration presented in Figures 10 and 11 indicates the need for a transition from manual systems to automated machining systems (such as CNC or auto-feed mechanisms) to ensure constant cutting force, improve product quality, and extend tool life.

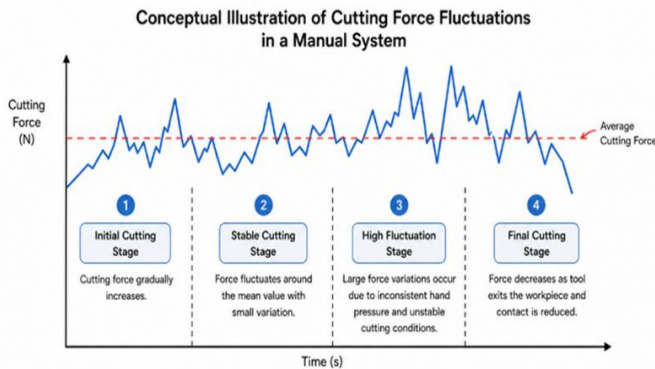


Figure 10: Conceptual illustration of cutting force fluctuations in a manual machining system

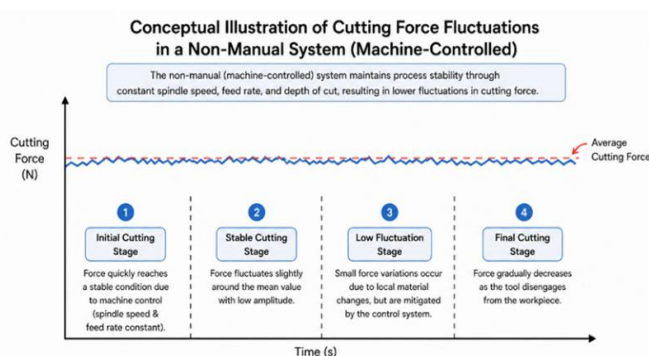


Figure 11: Conceptual illustration of cutting force fluctuations in a non-manual machining system

### 3.5 Evaluation of the Cooling System

The cooling system in the cutting process is applied manually and in a non-continuous manner [1,14]. The operator intermittently applies the coolant during machining. This application pattern results in non-uniform cooling distribution in the cutting zone [1,15]. Figure 12 shows the cutting fluid and brush used to cool the cutting process.



Figure 12: Cutting fluid applied manually using a brush

Unstable cooling conditions make it difficult to control the temperature in the cutting zone. The temperature tends to increase as the cutting process progresses. This heat accumulation accelerates cutting tool degradation [14,17–19].

The manual cooling system has several main limitations. Cooling distribution is not uniform across the entire contact area between the cutting tool and the workpiece. The system is unable to maintain a stable temperature throughout the machining process. In addition, dependence on the operator makes cooling consistency difficult to achieve [14,16].

These limitations reduce the effectiveness of the cooling system. The cooling rate is insufficient to balance the heat generation during cutting. This condition accelerates tool wear and reduces overall process performance [15,17,18].

### 3.6 Comparison of Alternative Methods

For the production process using an alternative method, namely a hand grinder, is employed to improve productivity. This method exhibits different characteristics compared to the hole saw method, as presented in Table 1.

Table 1: Comparison of Production Processes using the Hole Saw Method and an Alternative Angle Grinder Method

Method	Precision	Productivity	Tool Wear
Hole Saw	High	Medium	High
Grinder	Low	High	Low

The grinding method provides a higher material removal rate because it does not rely on a tooth-based cutting mechanism. The process is faster and does not require high operator force. However, the grinding method produces lower geometric quality compared to the hole saw process. The resulting surface is less precise and often requires additional finishing operations. Therefore, this method is less suitable for applications requiring high accuracy in pipe joining.

The selection of a cutting method should consider the balance between productivity and quality. The hole saw method is more suitable for applications requiring precision, whereas the grinding method is more appropriate fast production with looser tolerances.

### 3.7 Integrative Discussion

The results of the analysis indicate that cutting tool failure is the result of a complex interaction among material properties, thermal conditions, and process stability. These three factors continuously influence each other during the cutting process [14,16].

Stainless steel acts as a primary factor that triggers cutting tool wear. Its work hardening behavior increases material hardness during machining. This increase in hardness leads to higher cutting forces, which in turn accelerates the rate of tool wear [14–18].

Thermal effects further accelerate tool degradation through the increase of temperature in the cutting zone. Elevated temperatures reduce tool hardness and decrease resistance to deformation. This condition contributes significantly to the accelerated progression of cutting tool wear [1,14–16].

The manual machining system further aggravates the condition through process instability. Variations in feed force and spindle speed fluctuations result in non-constant cutting loads [14,16]. These dynamic loads accelerate tool wear through fatigue mechanisms at the cutting edge [15,17,18].

Manual machining systems can be categorized as high-variability systems. Process parameters cannot be consistently controlled during operation. This condition contributes to reduced machining quality and shortened tool life [14,16].

These findings indicate that cutting tool failure in manual machining systems cannot be explained by a single variable. The simultaneous interaction of thermal, mechanical, and operational factors is the primary determinant of overall process performance [1,14,16].

Process improvement approaches therefore require a holistic strategy. Temperature control, process stability, and appropriate tool selection must be addressed simultaneously to achieve optimal performance.

### 3.8 Engineering Implications

The results of this study provide several important implications in the field of manufacturing engineering. These implications can be directly applied to manual machining systems in industrial practice.

Process parameter control should still be implemented even in manual systems. Operators can be trained to maintain consistent feed force throughout the machining process. Such consistency helps reduce fluctuations in cutting load [14–16].

The cooling system should be improved to reduce heat accumulation. The use of more controlled cooling methods can extend cutting tool life [1,14,15]. An improved cooling system also contributes to better machining quality [1,16].

Cutting tool selection must be adapted to the material characteristics. Tools with higher thermal resistance can be used to enhance performance [14,15,17,18]. Proper tool selection can significantly reduce the wear rate [15,17,18].

These improvement approaches do not require large investments. When properly implemented, they can significantly enhance process performance within a relatively short time.

### 3.9 Limitations of the Study

This study is limited by the absence of quantitative measurements of temperature and cutting force during the machining process. The adopted observational approach focuses on qualitative analysis based on real industrial conditions.

Future research is recommended to integrate experimental measurements to strengthen result validation and improve the accuracy of the analysis.

## IV. CONCLUSION

This study shows that cutting tool failure in stainless steel pipe notching under manual machining conditions is a complex phenomenon influenced by the interaction of multiple factors.

Thermal effects are identified as the dominant factor contributing to the accelerated rate of cutting tool wear [1,14]. Stainless steel, with its low thermal conductivity, causes heat accumulation in the cutting zone. This condition significantly accelerates tool degradation [15,17,18].

Process instability due to the manual feeding system increases the variability of cutting loads [14,16]. This variability contributes to accelerated wear through fatigue mechanisms at the cutting edge [15,17,18].

The non-continuous cooling system further worsens the condition, as it is unable to effectively control temperature during the process [1,14,15].

Alternative methods such as grinding significantly improve process productivity. However, this method is less suitable for applications requiring high precision. Therefore, the selection of a cutting method must consider the balance between productivity and quality.

This study provides practical implications that can be applied in industrial settings, particularly in manual machining systems.

Improving the cooling system can reduce heat accumulation during the cutting process [1,14,19]. A reduction in temperature can extend cutting tool life [17,18].

Operator training can improve the consistency of feed force. This consistency helps reduce cutting load fluctuations and enhances process stability [14,16].

Selecting cutting tools that match material characteristics can improve process performance. Tools with higher thermal resistance can be used to reduce wear rates [15,17,18].

The use of alternative methods can be selectively applied according to production requirements. The grinding method can be used to increase productivity, while the hole saw method is more suitable for high-precision applications.

These recommendations do not require significant investment. Process performance improvements can be achieved through relatively simple enhancements to existing systems.

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