

# The Effect of Thread Depth on the Fatigue Strength of AISI 4140 Bolt Material as a Retainer and Fastener for a Screw Conveyor

Alvi Hidayat <sup>a</sup>, M. Dalil <sup>b,\*</sup> and Dodi Sofyan Arief <sup>b</sup>

<sup>a</sup>Magister Student, Department of Mechanical Engineering, Universitas Riau, Pekanbaru, 28293, Indonesia

<sup>b</sup>Department of Mechanical Engineering, Universitas Riau, Pekanbaru, 28293, Indonesia

\*Corresponding author: mdalil@lecturer.unri.ac.id

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## ABSTRACT

The bolts used to retain and fasten the shaft of the screw conveyor, which functions to transport wood chips to the cooking process in paper manufacturing, have experienced failure. The failure occurred in the form of a perpendicular fracture on the threaded section of the bolt. This damage significantly disrupts wood processing operations, making it important to investigate the causes. The causes of bolt fracture and its short service life were analyzed by studying the effect of thread pitch variations of 2.5 mm and 2 mm. The material tested was Valmet (VME), which is equivalent to AISI 4140. The fatigue test was conducted using a cantilever rotating bending method with the test specimens according to ASTM E466M standards. The results showed that to achieve infinite life, the stress level must be below 95 MPa. Thread pitch has a significant effect: VME bolts with a thread pitch of 2 mm showed a 17% longer endurance than bolts pitch of 2.5 mm.

**KEYWORDS:** Bolts, Pitch, Infinite Life, Endurance, Fatigue.

## NOMENCLATURE

ASTM	American Standard Testing and Material
VME	Valmet (VME)
N	Number of Cycles
S <sub>y</sub>	Fatigue Strength
SEM	Scanning Electron Microscope

## 1. INTRODUCTION

The bolts used to retain and fasten the screw conveyor shaft in transferring wood chips to the cooking process in paper manufacturing are damaged. The damage occurs on the threaded part of the bolt in the form of a perpendicular fracture of the bolt shaft. This damage significantly disrupts the operation of processing wood into paper in achieving optimum production capacity. Damage occurs every month, with an average of 5-24 bolts breaking per month. The breaking of these bolts disrupts wood processing operations because it requires 8-24 hours of repair time each month, in addition to the cost of procuring replacement bolts.

The bolts that are damaged are VME bolts with a pitch of 2.5 mm. After changing the bolt material to another AISI 4140 equivalent material, failures still occur within that time frame. The failed bolts showed a fatigue fracture interface [1] because no necking was found, and some of the fractures appeared perpendicular to the bolt cross-section. The failure position on the bolts was in the threaded part, as shown in Figure 1.



Figure 1: Bolt M20 ×110ISO 4762 as a fastener for the screw conveyor and gearbox that broke in 2024

Based on the analysis of the fracture location and the fracture shape that occurred at the threaded section, the most likely cause of the bolt failure was stress concentration at the thread as the trigger for the fracture [2]. This is supported by research findings stating that the higher the stress concentration, the faster a material will fracture [3]. The

higher the stress concentration value, the higher the crack rate will be [4]. Fatigue failure begins in areas of stress concentration and weak surfaces [5]. The failure position on the bolt occurs in the threaded section near the non-threaded shaft of the bolt at high cycles [6].

A number of studies have been conducted to determine the effect of threads on the fatigue resistance of a material. The conducted research on the characterization of the fatigue resistance of metric threads due to twisting bending loads on low carbon steel materials by conducting fatigue tests on specimens without metric threads, and with variations in depth of 0.33 mm, 0.67 mm, and 1 mm [7]. In addition, The conducted research on the characterization of Whitworth thread notch fatigue resistance due to dynamic torsion loading on low carbon steel by conducting fatigue tests on variations in Whitworth thread notch depths of 0.67 mm, 0.81 mm, and 1.16 mm [8]. The results of both tests show that the deeper the thread, the greater the decrease in fatigue cycles. The stress concentration that occurs at the end of the notch will increase the maximum stress experienced by the material and increase as the thread depth increases.

This study focuses on thread size. The thread pitch used on the broken bolts is 2.5 mm, and for metric bolts generally available on the market, there is also a thread size of 2 mm, thus opening up the possibility of using bolts with a pitch of 2 mm in an effort to find solutions to increase bolt durability. The objective is to analyze the effect of thread sizes with pitches of 2.5 mm and 2 mm on the durability of VME bolts used as retaining and fastening elements for screw conveyors, thereby identifying the most fatigue-resistant bolts.

The discovery of the main cause of bolt failure and solutions to improve bolt durability will be very beneficial for researchers, academics, and industry players who produce bolts, as well as bolt users from the general public and

industry. The discovery of the cause of bolt failure in this study will reduce maintenance and repair costs and benefit the industry because it can work optimally, without the disruption of repair time and repair and replacement costs.

## 2. METHODOLOGY

The method used in this study is an experimental method for material testing. The bolts are formed according to testing standards. Tensile test specimens are prepared without any treatment, only bolts formed according to the ASTM E8M tensile testing standard [9] as shown in Figure 2. Fatigue test specimens were prepared with variations in pitch size, namely 2.5 mm (depth 1.35 mm) and 2 mm (depth 1.08 mm) with metric thread standards. Fatigue test specimens were formed in accordance with the ASTM E466M fatigue testing standard [10],[11], as shown in Figure 3. The research material used was VME bolt material.

In addition to mechanical testing, this study also included chemical composition testing using XRF to determine the elemental content and material classification of the bolts. Information on chemical composition is needed to ensure material compliance with applicable standards and to assess its relationship with the resulting mechanical properties. In addition, testing was carried out using a Scanning Electron Microscope (SEM).

This test aimed to observe the morphology of the fracture surface, crack characteristics, and failure patterns that occurred in the specimens after fatigue testing [12]. With a combination of mechanical testing, chemical composition, and SEM, a more comprehensive analysis of fatigue resistance with the influence of the threads studied was expected to be obtained.

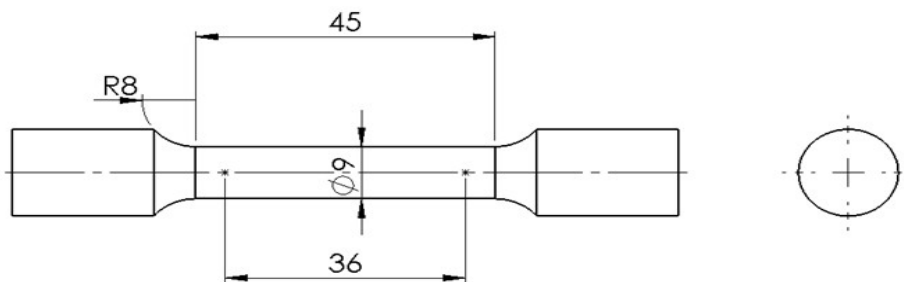


Figure 2: The dimension of the tensile test specimen complies with the ASTM E8M standard

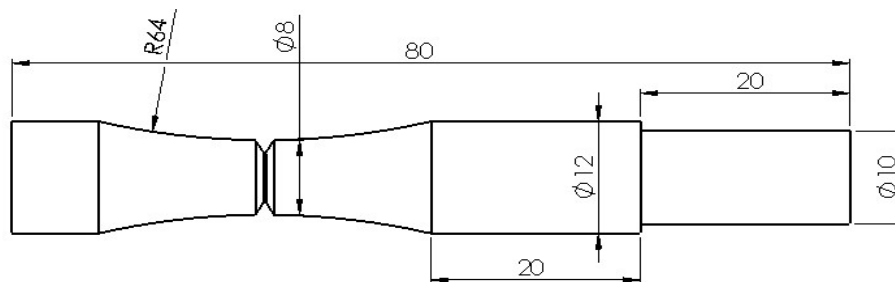


Figure 3: The dimension of the fatigue test specimen according to ASTM E466M standard

### 3. RESULTS AND DISCUSSION

This section presents the results and discussion of a series of tests that have been carried out, including chemical composition testing, tensile testing, fatigue testing, and analysis using a Scanning Electron Microscope (SEM). Each test provides complementary information, from the basic characteristics of the material to the morphology of the fracture. The results of each test can be seen in the Table 1. Based on Table 1, the VME bolts have tensile strengths of 1295.76 MPa, 1441.22 MPa, and 1475.79 MPa. Although high tensile strength provides an advantage in withstanding loads, there is a disadvantage in that materials with high tensile strength are generally more vulnerable to brittleness.

Figure 4 shows the fracture interface of the fatigue specimen. Examination of the fracture interface on the fatigue test specimen shows three characteristic zones. The crack propagation zone (B) displays a concentric circular pattern (beach marks), which is evidence of stable crack growth due to cyclic loading. The final fracture zone (C), which is darker in color, is the area of rapid fracture in the final cycle and has a rough texture that indicates sudden fracture when the remaining cross-section is no longer able to withstand the load. At the edge of the surface, the crack initiation zone (A) is visible as the starting point of the crack and is clearly shown in Figure 5 using SEM.

In VME bolt material, as seen in Figure 5, the initial crack originated from a very fine and relatively short micro-crack with a length of 1 mm. The crack initiation surface is smoother and does not show significant plastic deformation around the crack tip. This characteristic indicates that VME material has a more homogeneous microstructure and is able to withstand local stress well, so that the crack initiation process takes place more slowly [13], as proven in the fatigue test in Table 1.

The fracture interface in this study, as describe in the ASM International Handbook Committee [14], shows that fatigue fractures occur due to rotating bending loads, which is consistent with the fatigue testing scheme. Figure 6 shows the fatigue failure scheme.

Table 1: Results of chemical composition, tensile, and fatigue testing of VME bolt material

Spesifikasi Material	VME
Carbon (C)	0.650 %
Mangan (Mn)	0.779 %
Chrome (Cr)	1.140 %
Molybdenum (Mo)	0.190 %
Zinc (Zn)	0.300 %
Titanium (Ti)	0.160 %
Nickel (Ni)	-
Yield Strength (Mean)	1262.23 MPa
Tensile Strength (Mean)	1295.76 MPa
Tensile Strength (HRC)	1441.22 MPa
Tensile Strength (HV)	1475.79 MPa
Strain	11.00 %
Fatigue Strength dan Number of Cycles (pitch 2.5 mm, 80 N)	103.197 MPa 531960 cycles
Fatigue Strength dan Number of Cycles (Pitch 2 mm, 80 N)	107.565 MPa 640640 Cycles

In terms of alloying elements, VME bolts are a special production material designed to have good hardness and corrosion resistance, characterized by the presence of alloying elements such as Ti, Zn, and Cr. In addition, the absence of Ni (nickel) in this material indicates that the increase in toughness and strength stability does not depend on nickel, as is commonly done in high-alloy steels.

In Table 1 also shows the results of tensile testing using a Universal Testing Machine (UTM), which indicates that VME bolt material has a tensile strength value of 1295.76 MPa, categorizing this material as high-strength steel. The strain parameter on the specimen was 11%, with a cross-sectional reduction percentage of approximately 49–54%, indicating good plastic deformation capability before fracture. These values show that VME bolts have balanced mechanical characteristics, namely high tensile strength combined with good ductility.

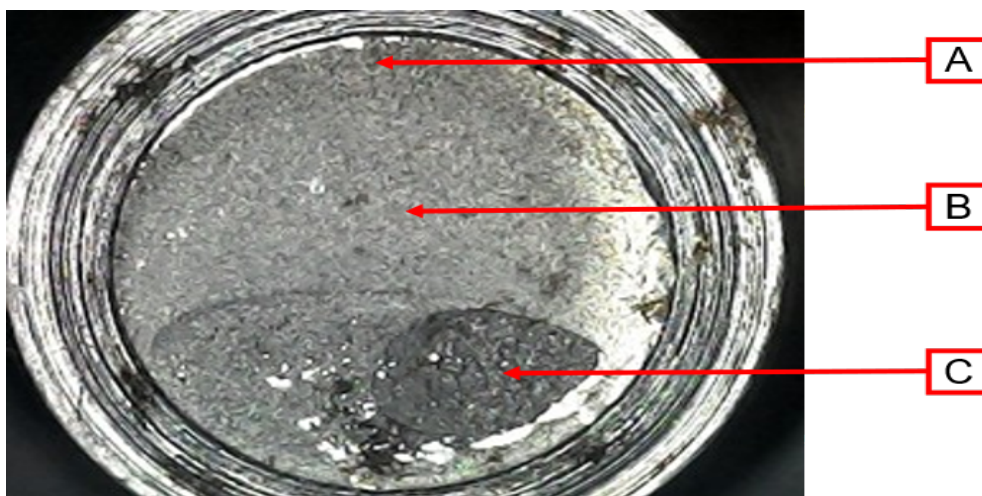


Figure 4: Interface Fracture Specimen Results of Fatigue Testing of VME Bolt Material under 8 kg Load [A] crack initiation area [B] crack propagation area [C] final fracture area

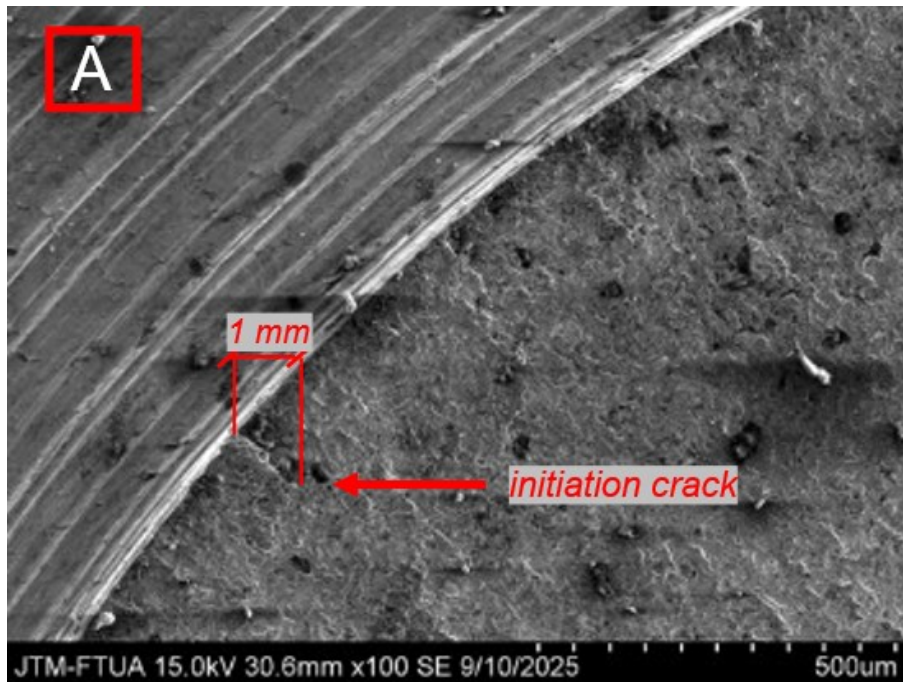


Figure 5: Observation of the initial crack area of VME bolt material with SEM x100

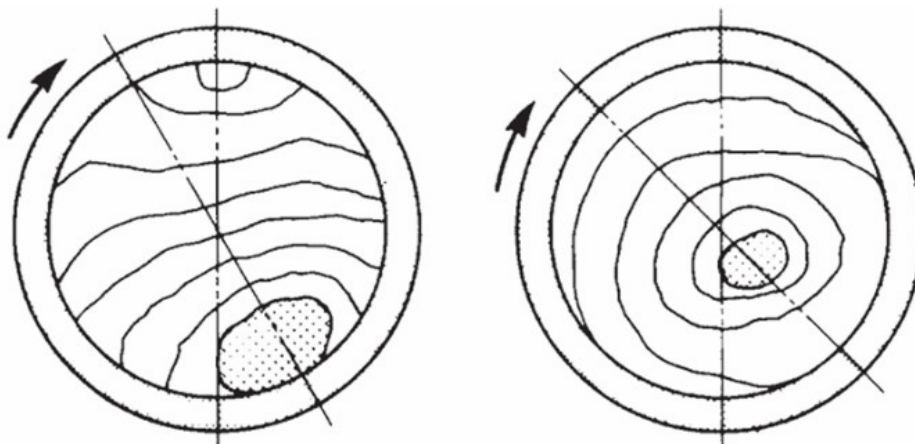


Figure 6: Fatigue Failure Schemes

Furthermore, the hardness test data also supports this finding, with a hardness value correlated with an average tensile strength of 1441.22 MPa, indicating that VME bolts have undergone heat treatment to increase their mechanical strength. The combination of high tensile strength and sufficiently high strain values indicates that VME bolts are capable of performing well under loading conditions that produce repeated micro deformation, such as in rotation-based machine components.

Although high tensile strength is a key advantage of this material, this property has the potential to increase the material's vulnerability to brittle failure. High-strength materials tend to have more limited plastic deformation

capacity, so failure can occur suddenly without significant deformation as an early warning sign [15]. Therefore, in industrial applications such as screw conveyor bolts that operate under dynamic loads, special attention is required in material selection to consider the balance between strength and toughness, so that the operational performance and reliability of the components can be maintained.

### 3.2 Discussion of the Fatigue Strength

The results of fatigue testing of VME bolts using a rotating bending fatigue testing device in accordance with ASTM E466M are shown in Figure 7.

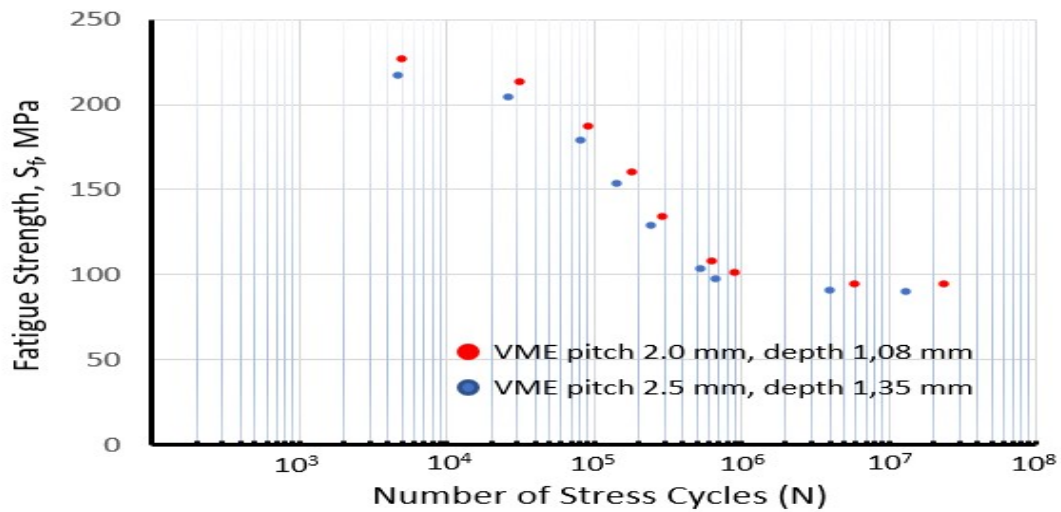


Figure 7: S-N curve resulting from fatigue testing

The results of fatigue testing on VME bolt materials with thread pitch variations of 2.0 mm (depth 1.08 mm) and 2.5 mm (depth 1.35 mm) are shown in Figure 4. In general, the curve shows a trend of decreasing fatigue strength values as the number of loading cycles increases, which is a common characteristic of fatigue failure. Bolts with a pitch of 2.0 mm showed higher fatigue strength values across almost the entire cycle range compared to bolts with a pitch of 2.5 mm. This condition indicates that thread depth has a significant effect on fatigue resistance, where the greater the thread depth, the greater the stress concentration at the base of the thread, which accelerates the crack initiation process. In addition, rough surfaces on threads during finishing can be the initial cause of fracture [16].

When viewed from the results of the chemical composition analysis in Table 1, VME bolt material is known

to contain alloying elements such as Mo, Ti, and Cr, which play a role in increasing resistance to crack growth (fatigue crack growth). Ti and Mo elements serve to refine grain size and increase grain boundary strength, thereby preventing the propagation of microcracks from one grain to the next [17],[18]. The combination of high tensile strength and good ductility allows VME bolt material to absorb greater deformation energy before cracks propagate, thereby extending fatigue life.

Thus, the shallower thread geometry (pitch 2.0 mm) and alloy composition that supports microstructure strengthening are dominant factors in improving the fatigue performance of VME bolt material. This material shows good potential for dynamic applications, especially in machine components that experience continuous cyclic loads, such as bolts in screw conveyors.

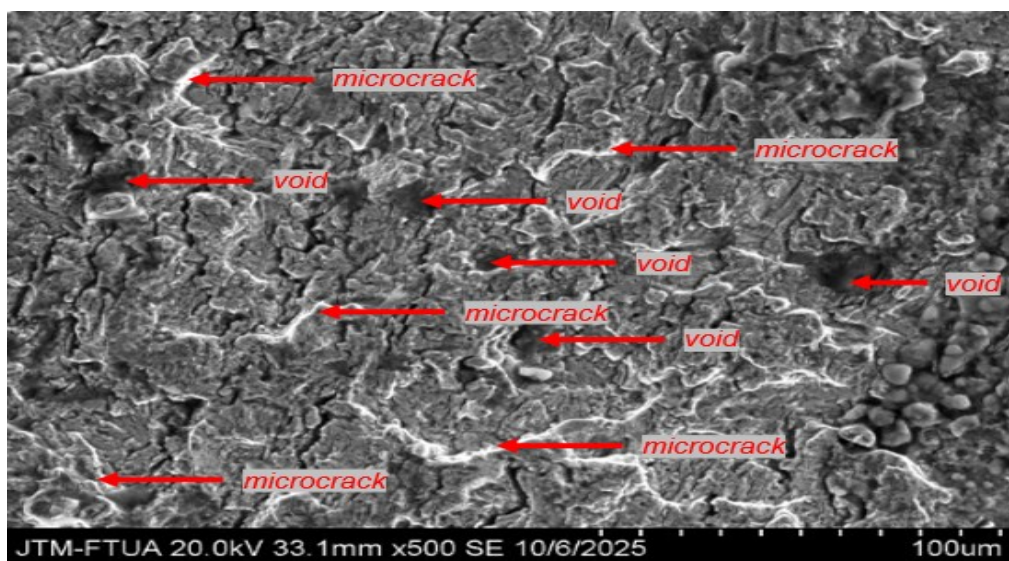


Figure 8: Interface of VME Bolt Material Fracture with SEM 500x

The results of Scanning Electron Microscope (SEM) observations at 500x magnification in Figure 8 on the VME bolt material show the morphology of the fracture surface, which is characterized by the presence of fine, uniform micro-cracks that are interconnected at several points along the fracture path. This pattern indicates that crack propagation occurs gradually and steadily, with controlled micro-damage accumulation during cyclic loading. In addition to micro-cracks, very small voids are also visible, formed due to local plastic deformation before final fracture occurs. The small size of the voids and the dense distribution of micro-cracks indicate that crack coalescence occurs slowly, so that the effective cross-section of the material is still able to withstand loads for a longer number of cycles before total failure. Voids are the starting point for cracks to spread, and voids often form at the interface between phases [19]. If there are more voids, and they are larger and easier to form, the material will be more ductile. And if there are fewer voids, and they are smaller and not as easy to form, the material will be more brittle. An effective way to predict the presence of voids, which are an indication of failure, is to use the Finite Element Method [20].

#### 4. CONCLUSION

VME bolts used in wood chip screw conveyors must have a stress lower than 95 MPa to achieve infinite life and prevent failure. The effect of thread pitch depth on failure is significant; VME bolts with a 2 mm thread pitch show 17% longer durability than bolts with a 2.5 mm pitch. The VME bolt material has fine, short cracks that do not cause significant plastic deformation on the stress concentration surface. Additionally, it has small voids and more evenly distributed micro-cracks, allowing for gradual crack growth with longer fatigue cycles to withstand loads.

#### 5. ACKNOWLEDGEMENTS

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