# Investigating Effects of Surface Roughness and Hanging Load on Fatigue Life of Mild Steel

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**Abstract**: Fatigue analysis has been a widely studied field, with mild steel being a popular alloy due to its affordability, durability, and other beneficial properties. In order to improve efficiency and quality, techniques related to Hybrid friction stir welding have been developed, and surface roughness has been identified as a key factor affecting the fatigue life of materials. This research aims to study the impacts of varying surface roughness along with hanging load on the fatigue life of mild steel using hybrid friction stir welding techniques. The results of this study provide valuable insights for engineers and manufacturers to make informed decisions when selecting materials and designing structures to withstand the stresses of cyclic loading.

**Keywords:** *Fatigue analysis, mild steel, surface roughness, hanging load, welding current*

## I. INTRODUCTION

Fatigue failure is a substantial factor constraining the growth of machinery as well as equipment, alleviating its working life, and affecting the accuracy of processing as well as safe production as many types of equipment move toward high speed and high precision with the modern industry development. Accidents brought on by fatigue failure do occasionally occur. The Aloha Airlines Flight 243 Boeing 737 accident, the Delta Air Lines Flight 1288 MD-88 tragedy, and the Meudon railway disaster in 1842, all had fatigue breakdown of essential components as their primary cause. As a result, fatigue damage's severity and significance are becoming more widely acknowledged [1,3]. Because of its chemical characteristics, mechanical strength, weldability, and machinability, mild steel is a commonly utilized alloy that is crucial to many industries. Additionally, processes like acid-pickling, acid-cleaning, and acid-descaling are used in numerous sectors to clean and prepare the surface of steel products. [2,3,4]

The affordability of mild steel is a significant benefit. Mild steel is a far more cost-effective choice than other metals like stainless steel or aluminum for those looking to save money without sacrificing quality. Mild steel is very resilient along with being reasonably priced. It is quite strong and won't break or corrode even after many uses. Because of its good weldability as well as ease of shaping into numerous shapes, mild steel is easier to deal with. Ultimately, mild steel is capable of tackling high stress levels without buckling or cracking due to its excellent tensile strength.

Localized coalescence (permanent junction) is produced during the welding process with or without the application of heat, pressure, or heat alone, as well as with or without the introduction of filler material to join comparable or different materials. In welding, two welded materials fuse together in order to develop a permanent bond. Often, filler material is given to the joint to strengthen it. A welded junction is more durable and cost-effective. Mild steel is one among the more affordable types of steel and is widely utilised in all applications. Any basic welding technique might be utilised to weld it with ease. It can rust when it comes in contact of oxygen but still it is very hard and durable. When a big amount of iron is needed, it is used. When a large amount of iron is required, it is used. It has a maximum carbon content of 0.29%, a maximum manganese content of 0.9%, and only trace amounts of silicon, phosphorous, and sulphur. It allows for the simple passage of electrical current without having any impact on the internal structure of the metals. Compared to steel, it has better welding qualities. [5,6]

Fatigue life analysis of a material is important to understand its potential to handle cyclic loading conditions over a period of time. It is a crucial factor in the design and performance of various engineering components such as aircraft structures, bridges, machine parts, and more. Understanding a material’s fatigue life can help in designing and selecting materials that can withstand repeated loading and have a longer service life, thus improving the reliability and safety of the components. Additionally, the analysis can provide insights into the effects of different factors on the fatigue life of a material, such as surface roughness, welding parameters, and environmental conditions, that might be utilised to optimize the design and manufacturing processes.

## II. LITERATURE REVIEW

Recent advancements in the area of automotive materials include weight reduction of automotive materials to alleviate the environmental load as well as workability improvement to increase global competitiveness. Steel materials need to have extremely high tensile strength and be able to handle complicated structures of high-performance components in such circumstances. The demand for thick and highly tensile steel products in the steel pipe and thick plate industries is high because of the mega-structural construction trend and high efficiency transportation. Innovative welding techniques are required to completely utilise such cutting-edge steel products, and as steel materials have improved, so have the welding techniques themselves. The developments and practical uses of state-of-the-art welding technology in JFE Group are addressed in Oi, K. et al.'s [1] report. In a study solid state welding and application in aeronautic industry have been researched by Akca, E et. al. [2]. In fact, a method that enables comparable as well as dissimilar metals to be welded together is solid state welding, and it is utilized in the industrial production fields of aviation, nuclear, space, and aeronautics, among others. It has conventionally been assumed that welding impacted by high-velocity is a solid-state production process. According to Nassiri, A et al. [3], the correlations between the microstructural defects' development within the bonding area as well as melting events were established with a combination of advanced interfacial characterizations, meshfree numerical simulations, along with diffusion calculations. In addition , it was deduced that the development of considerable grain refinement near the weld interface might be related to melting and subsequent recrystallization as an output of the high pressure impact process' extremely rapid heating and cooling rates. The new outcomes refute the conventional belief on the solid-state properties of impact-based welding methods. El Mahallawy, N., et al. [4] used commercially available pure Al 1050 as well as Al-12%Si alloy sheets to produce multi-layered Al/Al-12%Si composites through accumulative roll bonding (ARB) at ambient temperature. Scanning electron microscopy (SEM) was used to describe the microstructures of the Al and Al-12%Si alloy layers. Vickers microhardness as well as tensile tests were performed to look into the composites' mechanical characteristics. It was expected that as the number of ARB cycles increased, the thickness of the individual Al and Al-12%Si alloy sheets dropped, and at the second cycle, the Al-12%Si layers were finally necked. A multi-layered Al/Al-12%Si composite with uniformly spaced Al-12%Si layers in aluminum matrix was created after the second ARB cycle. Si phase's length was lowered from 65.6 to 25.57 m, while the size of the Al grain was decreased from 25 to 7.2 µm. X-ray diffraction proved that the intermetallic phase Al3.21Si0.47 had formed after the second cycle. The results showed that after the first cycle, the tensile strength grew up to 270 MPa and then decreased. Microhardness analysis showed that as the number of ARB cycles spiked the hardness of the individual layers increased consistently. In his study, N.E. Mahallawy et. al. [5] used accumulative roll bonding (ARB) to produce multilayered composites comprised of Al/Al-12%Si at 300°C. The microstructure and mechanical properties of the composites were investigated through a number of ARB cycles using a tensile test, a Vickers microhardness test, a field emission scanning electron microscope (FE-SEM), and other techniques. According to the FE-SEM outcomes, the thickness of individual Al and Al-12%Si sheets decreased as the ARB cycle increased. After the fifth cycle, the Al-12%Si layers were necked, fractured, and disseminated throughout the aluminum matrix. The production of the unique intermetallic phase Al3.21Si0.47 at the Al/Al-12%Si interface raises the possibility that metallurgical bonding may result from the ARB process. The tensile strength of composite materials was demonstrated to rise with the number of ARB passes; for instance, the tensile strength of the Al/Al-12%Si composite was measured to be about 5.52 and 2.17 times that of the primary 1050-Al and Al-12%Si sheets, respectively. Observations show that composites that have undergone ARB processing experience the shear ductile rupture type of failure. The microhardness of Al and Al-12%Si alloys increased to 110 HV and 121 HV after five cycles, respectively. Ni, Z et. al. [6] Since it is a solid joining technique, ultrasonic spot welding is a potential spot welding process to construct the aluminium alloy connections. This paper reviews the state of ultrasonic spot welding for joining of aluminium alloys and discusses a number of important issues, like general process parameters, materials flow, interfacial temperature, stress distribution, interfacial shear force, microstructure, macrostructure, relative motion, mechanical properties along with strengthening mechanisms. Future trends in the industry are also noted. Ahmed G M S, et. al. [7] Vibration is a frequent problem in turning operations, which has an impact on the machining outcome, particularly the surface finish. Vibrations also have an impact on the life of tools. Dynamic motion between the work piece and cutting tool commonly causes loud acoustic noise in the workplace. Vibrations are produced throughout all cutting operations, including turning, boring, and milling, as a finding of the work piece being deformed. Choosing the right machining parameters is particularly significant during turning since it defines the required degree of surface quality. A parameter that hasn't received as much attention as some of the more well-known ones is cutting tool overhang. Although a longer tool overhang may be needed when using the hole turning process in particular and depending on the geometry of the work piece, it should be maintained to a minimum. In this study, we investigate the impact of tool overhang changes on tool wear and work piece surface quality during external turning. For this project, they used work pieces with diameters of 20, 30, and 40 mm that were produced of AISI 1050 steel. They experimented with constant cutting speed along with feed rates with different depths of cuts (DOCs) and tool overhangs to determine the surface roughness of the work piece. We found that tool overhang is more significant than the DOC in terms of impact on surface roughness. Tool overhang causes the cutting tool's deflection to rise. The effect of tool deflection on tool overhang was examined using two different analytical methods. Also, a comparator was utilised to establish the actual tool deflection values. We found that the tool deflection values and the tool deflection findings from the second analytical method were quite compatible. In their study, Patwari A U, Alfakih Y M and Bamnjo I et. al. [8] analysed the impacts of tool overhang on machining reactions to chip shape and surface roughness are experimentally examined. Using a carbide cutting insert covered with TiC, machining tests were conducted on a standard lathe machine. Three levels of overhang length, ranging from 20 to 70 mm, were chosen as the cutting variable while maintaining a constant depth of cut, feed rate, and rpm. It was found and established through the use of graphical and observational methodologies that the overhang length significantly affected both the surface roughness and chip behaviour. These tests resulted in the identification of the ideal overhang length value with favourable surface finish quality and minimal tool wear.

## III. METHODOLOGY

### Fatigue-Life Methods

The 3 primary fatigue life methods used in design and analysis are as under.

- Stress-life method,
- Strain-life method, and
- Linear-elastic fracture mechanics method.

Low-cycle fatigue is generally defined as life of $1 \leq N \leq 10^3$ cycles, and high-cycle fatigue is defined as $N > 10^3$ cycles. The least accurate method, particularly for low-cycle applications, is the stress-life method, which simply considers stress levels. The fact that it is the simplest to use for a variety of design applications, has a wealth of supporting evidence, and accurately depicts high-cycle applications makes it the most often used approach. With the strain-life technique, life is estimated by looking more closely at isolated areas of plastic deformation where stresses and strains are both present. Applications involving low-cycle fatigue benefit particularly from this technique. The outcomes of this procedure will be a bit unpredictable because several idealizations must be combined.

The existence of an identified crack is assumed in the fracture mechanics approach. The forecasting of fracture growth in relation to stress intensity follows. When utilised in conjunction with computer codes as well as a routine inspection software, it works well for large structures. The estimate of fatigue life can be obtained by incorporating the Paris crack growth law if the Stress Intensity Factor range lies inside the second region, the linear region.

$$\int_{N_o}^{N_f} dN = \int_{a_o}^{a_f} \frac{da}{C(\Delta K)^n}$$

The aforementioned equation might be used to compute the size of a crack for a fixed number of loading cycles or the number of fatigue cycles, $N_f - N_o$ required for $a_o$ to grow to a certain size. However, as the $a_f$ and $N_f$ are frequently intricate functions of both the fracture shape and stress in practical applications, $\Delta K$ is typically challenging to develop an analytical relation between them.

Two forms of Euler integration

$$N_{m+1} = N_m + \frac{\Delta a}{C[\Delta K(a_m)]^n} \qquad m = 0,1,\ldots\ldots\ldots,n$$

$$a_{m+1} = a_m + C[\Delta K(a_m)]^n.\Delta N \qquad m = 0,1,\ldots\ldots\ldots,n$$

Where

$\Delta a$ = Crack growth increment is taken as a constant,

$$\Delta a = \frac{(a_f - a_0)}{n}$$

n is the number of intervals used during the numerical integration process. Reduce the value of $\Delta a$ to achieve the required integration precision. Theoretically, if the value is assumed to be infinitesimal, the solution will converge to the right answer, but it will undoubtedly take a long time to compute. The $\Delta K$ for these crack sizes, $a_m$, during the crack growth should be computed using some numerical techniques, such as the finite element method. It is possible to predict the number of fatigue cycles as long as these $a_m$ values are known.

A fatigue testing machine is a mechanical testing device used to subject materials or components to cyclic loading conditions to determine their resistance to fatigue failure. The machine typically consists of a hydraulic or electric actuator that applies cyclic loads to the specimen through a grip or fixture. The machine also includes a load cell, displacement sensor, and control software to measure and record the applied load and specimen deformation. The test specimen is usually prepared according to the required standards and is mounted between the grips. The test is conducted until the material or component fails or reaches a predetermined number of cycles. Fatigue testing machines are commonly used in various industries, including aerospace, automotive, and construction, to assess the durability and reliability of materials and components under cyclic loading conditions.

**Figure 1 Fatigue testing machine**

**Figure 2 Brake fatigue specimen**

The brake fatigue specimen is subjected to repeated cycles of braking and release, with the number of cycles and the force applied during each cycle being carefully controlled and monitored. The purpose of this testing is to evaluate the ability of the brake material to withstand the repeated stresses and strains that occur during use, and to determine its resistance to failure due to fatigue. The results of brake fatigue testing might be utilised to evaluate the performance of different brake materials and to identify the most durable and reliable options for use in various applications. This information can be critical in the design and selection of brake systems for a wide range of vehicles and equipment, from cars and trucks to trains and airplanes.

## IV. RESULT AND DISCUSSION

This study focuses on the impact of surface roughness and hanging load levels on the fatigue life of mild steel and evaluates the effectiveness of hybrid friction stir welding techniques to improve welding quality and efficiency. The section discusses the extensive research conducted on fatigue analysis and the use of mild steel in various industries. The results of this investigation are presented in detail in this section.

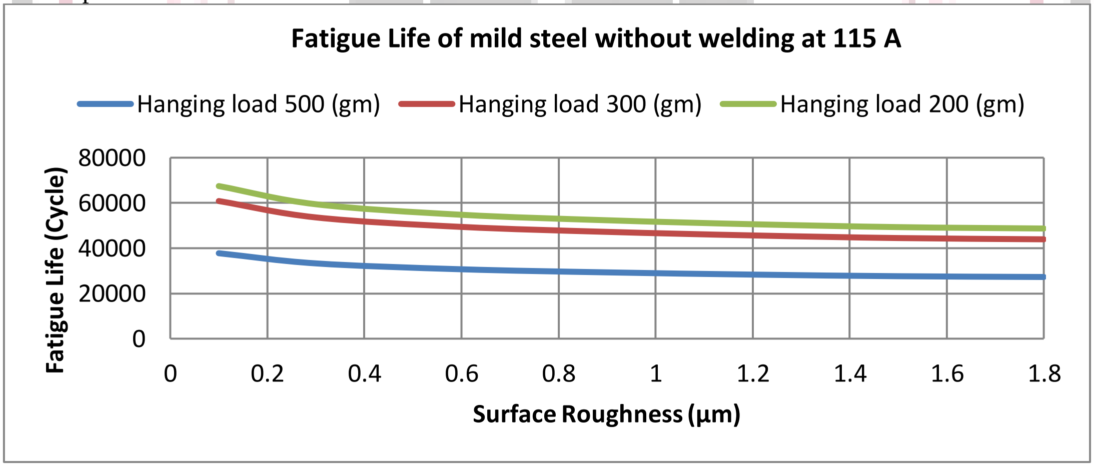

**Figure 3 Fatigue Life of mild steel without welding at 115 A**

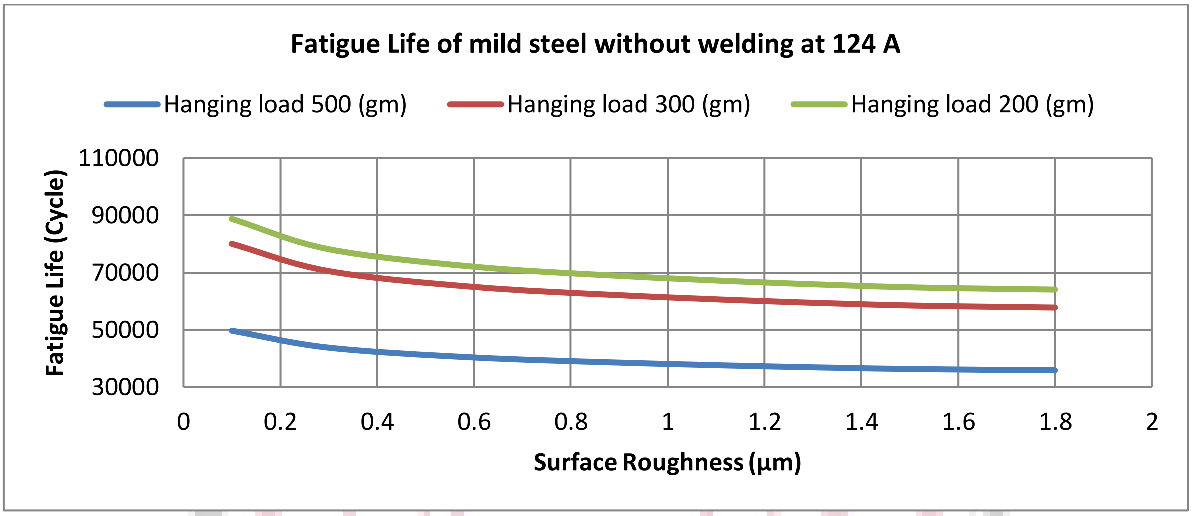

**Figure 4 Fatigue Life of mild steel without welding at 124 A**

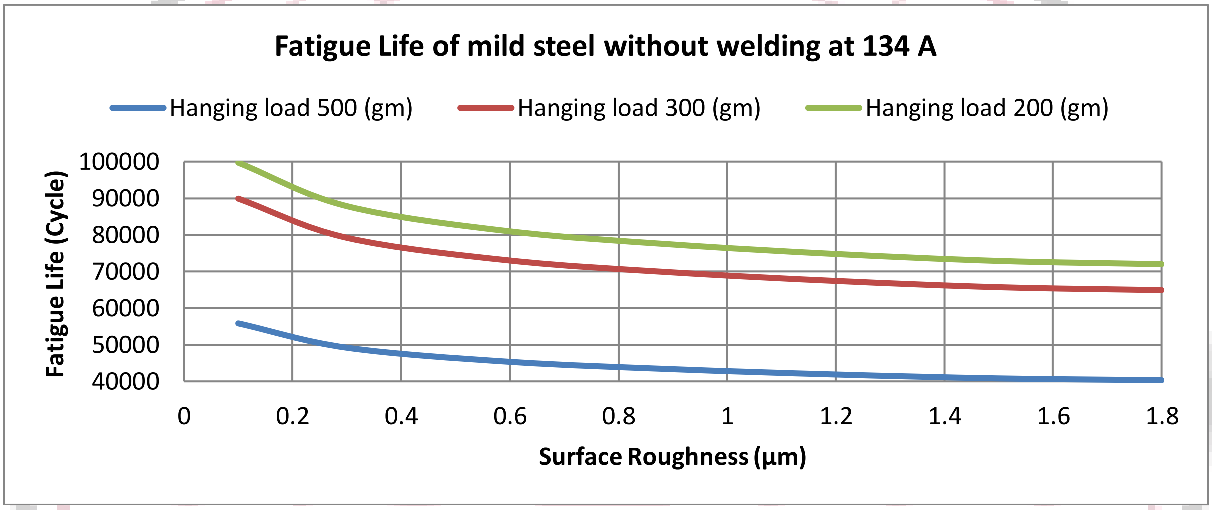

**Figure 5 Fatigue Life of mild steel without welding at 134 A**

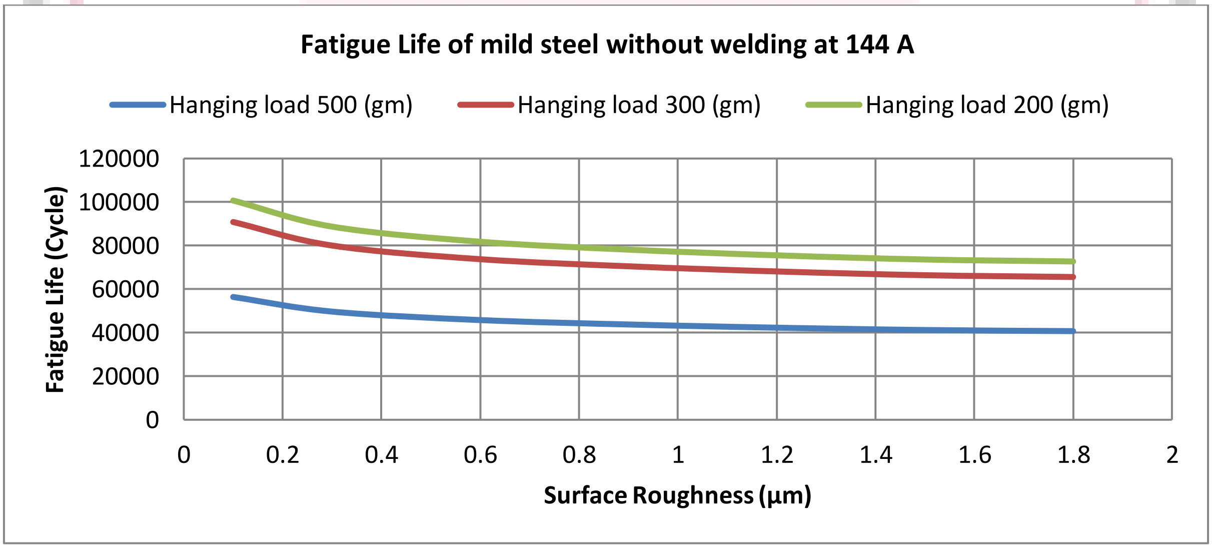

**Figure 6 Fatigue Life of mild steel without welding at 144 A**

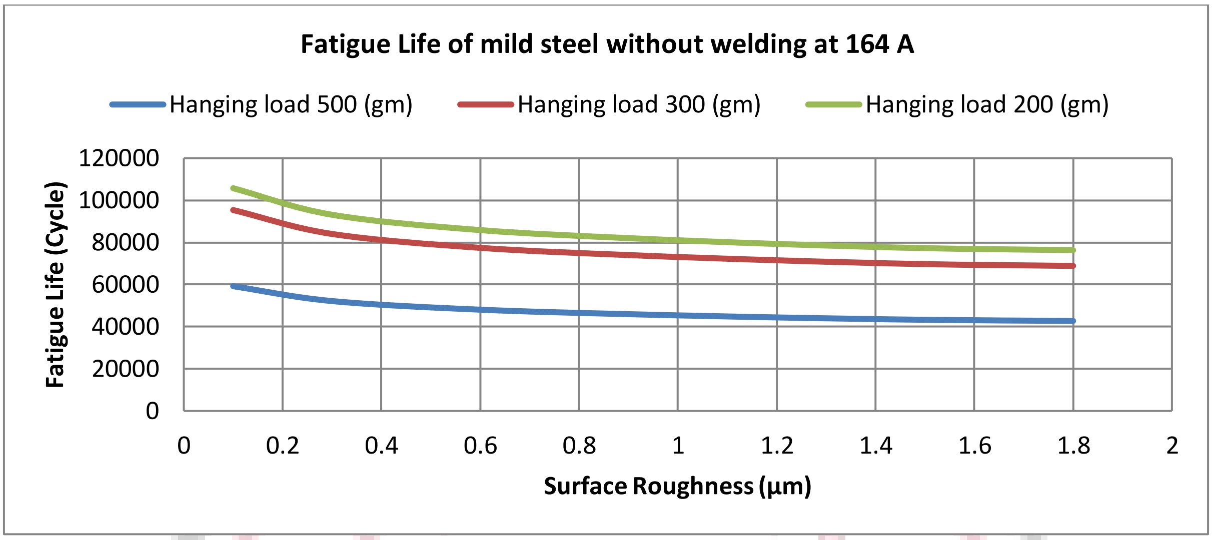

**Figure 7 Fatigue Life of mild steel without welding at 164 A**

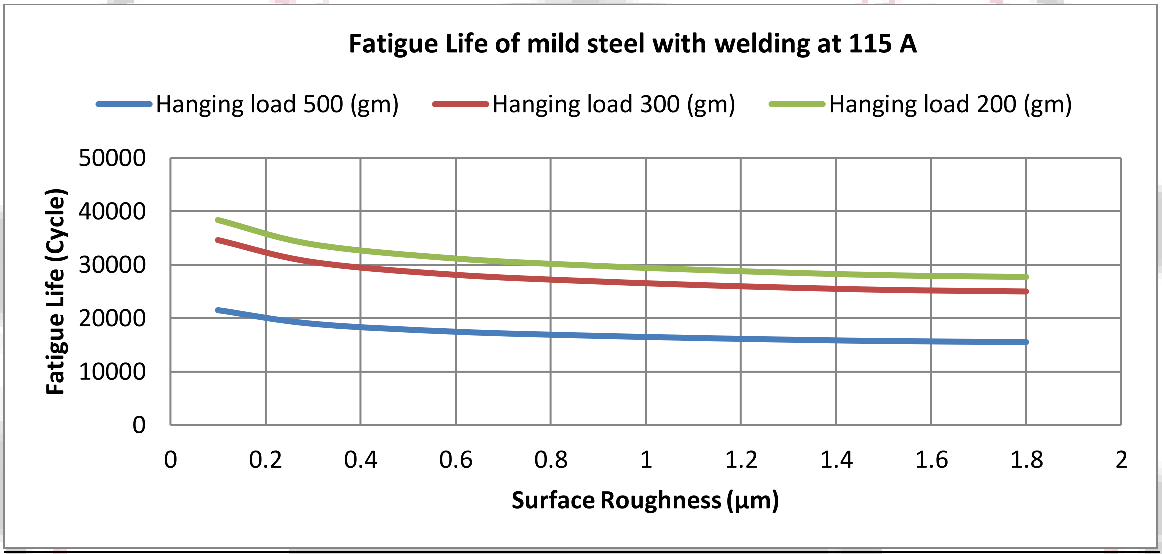

**Figure 8 Fatigue Life of mild steel with welding at 115 A**

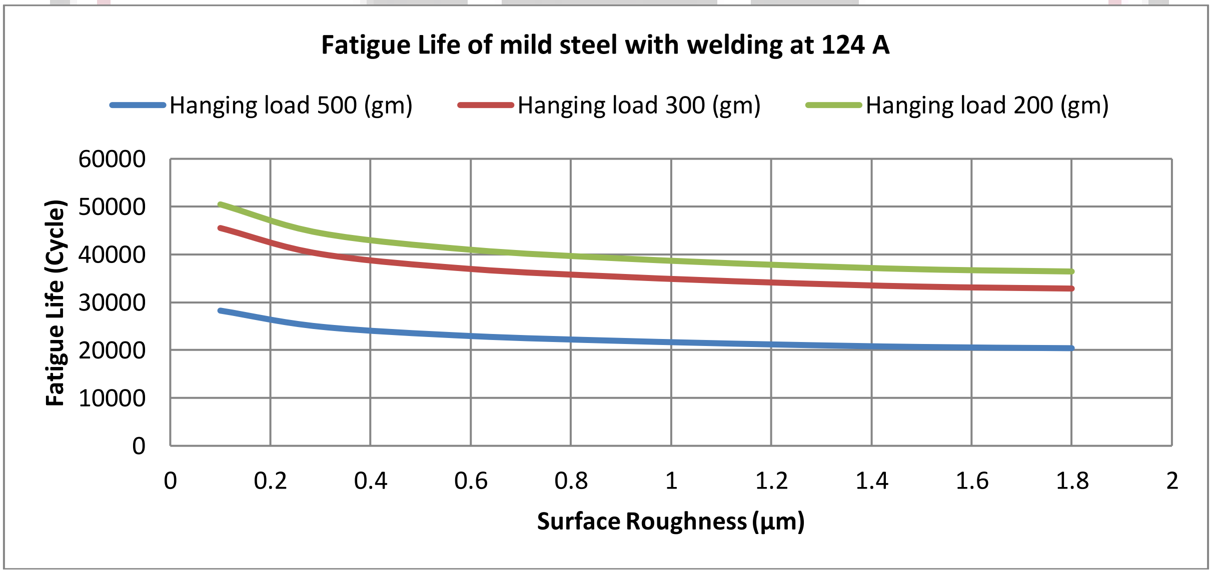

**Figure 9 Fatigue Life of mild steel with welding at 124 A**

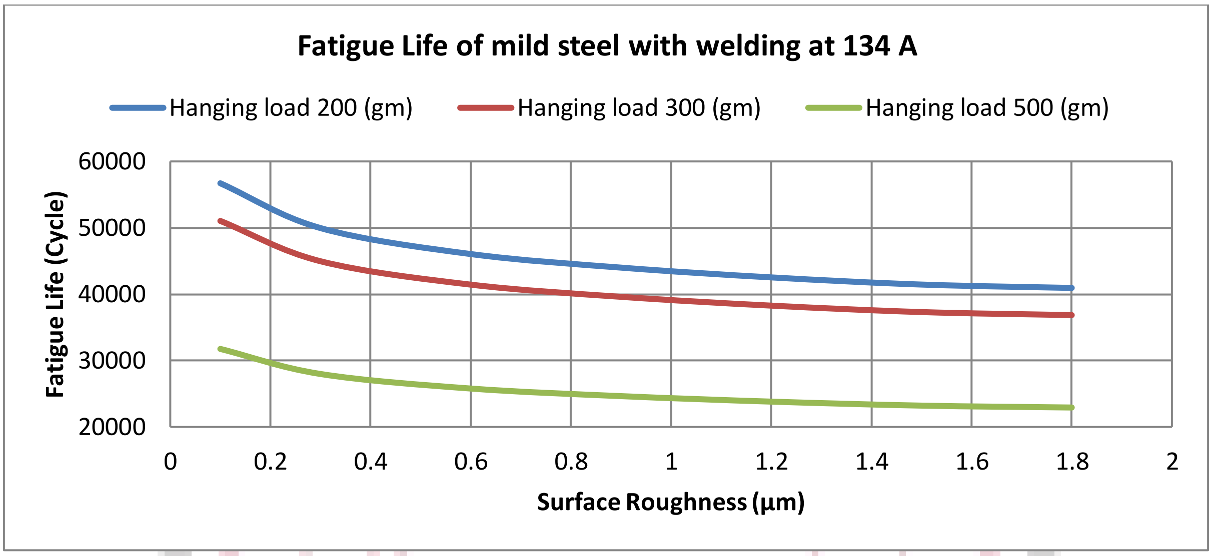

**Figure 10** **Fatigue Life of mild steel with welding at 134 A**

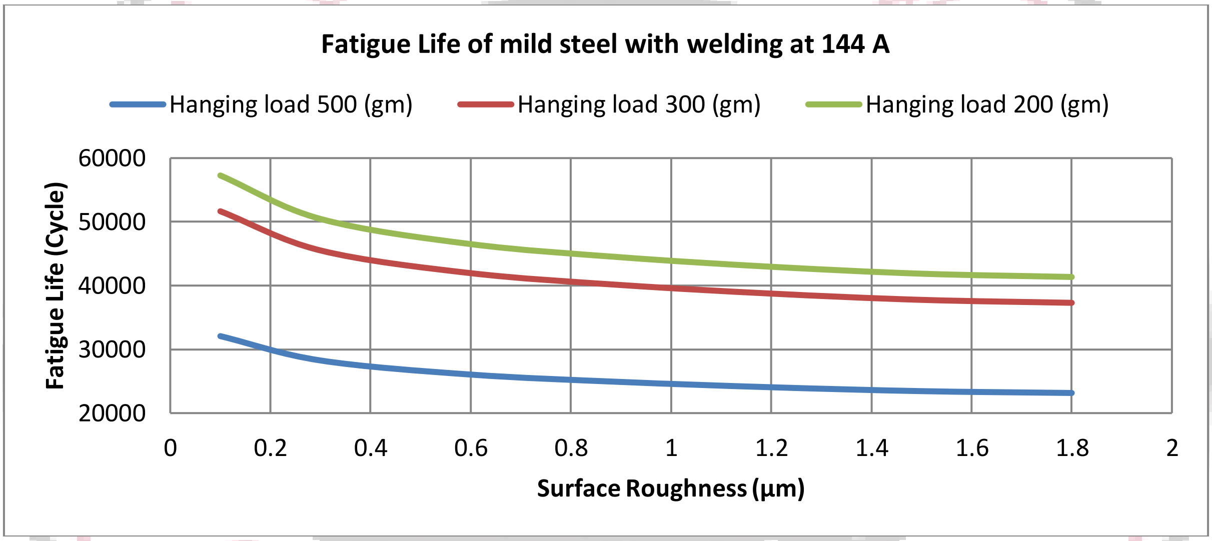

**Figure 11** **Fatigue Life of mild steel with welding at 144 A**

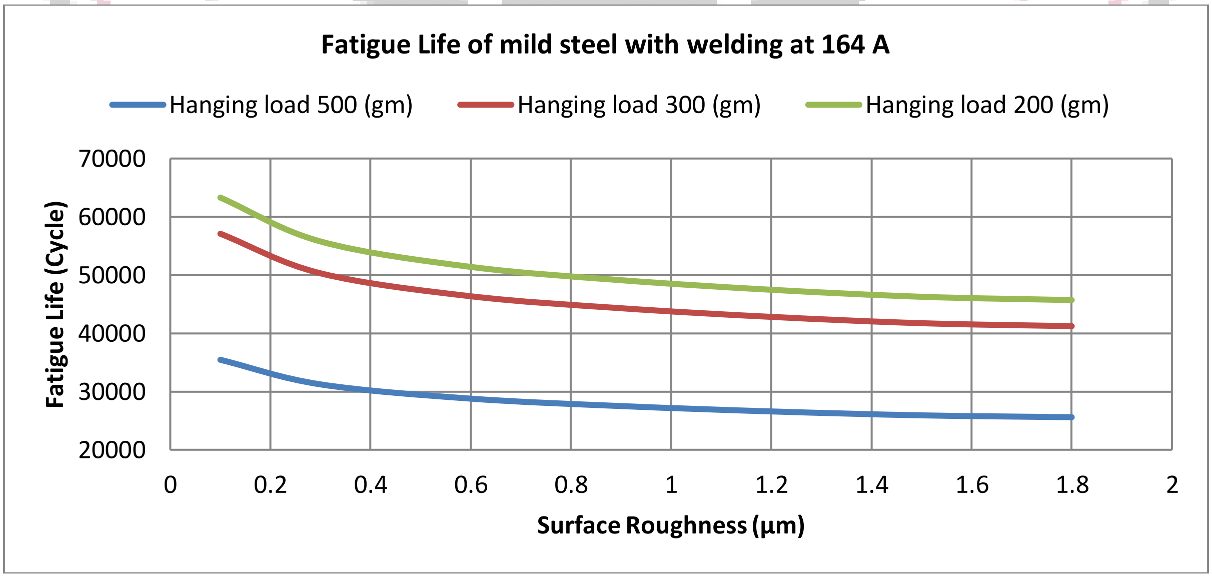

**Figure 12** **Fatigue Life of mild steel with welding at 164 A**

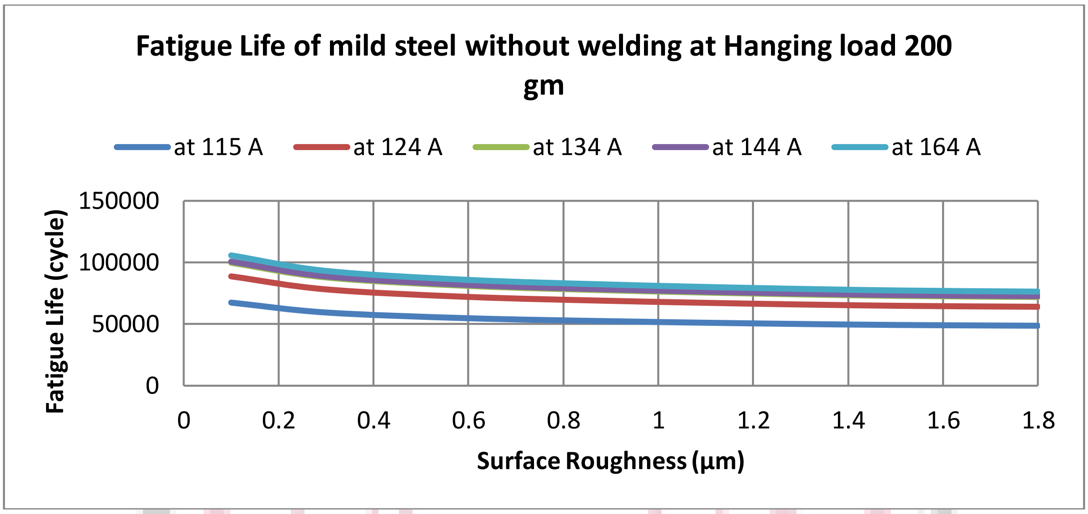

**Figure 13 Fatigue Life of mild steel without welding at hanging load 200 gm**

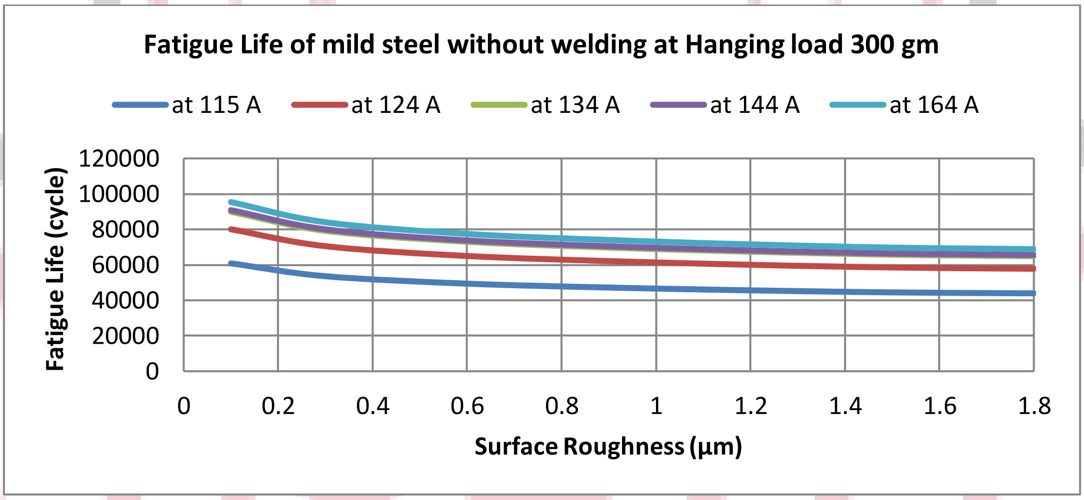

**Figure 14 Fatigue Life of mild steel without welding at hanging load 300 gm**

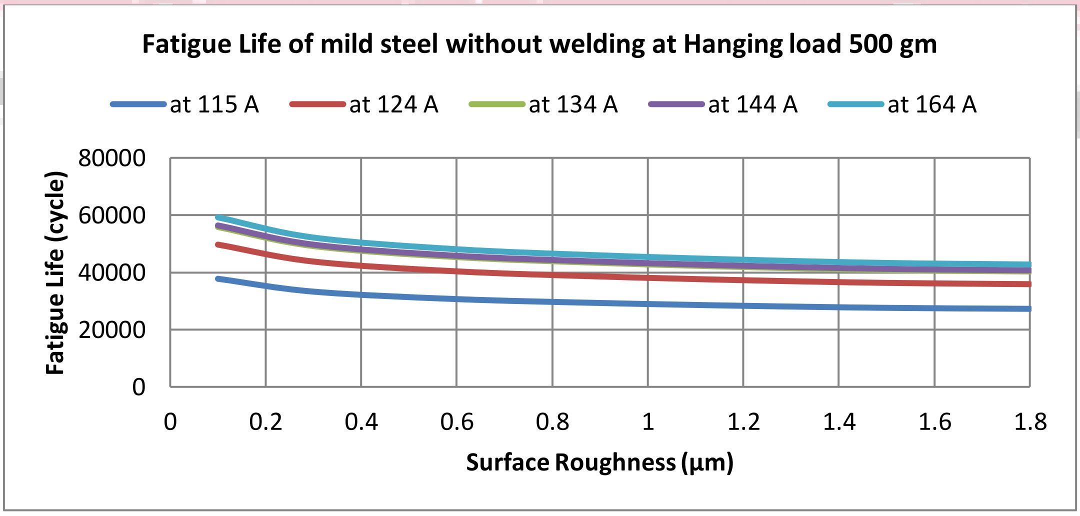

**Figure 15 Fatigue Life of mild steel without welding at hanging load 500 gm**

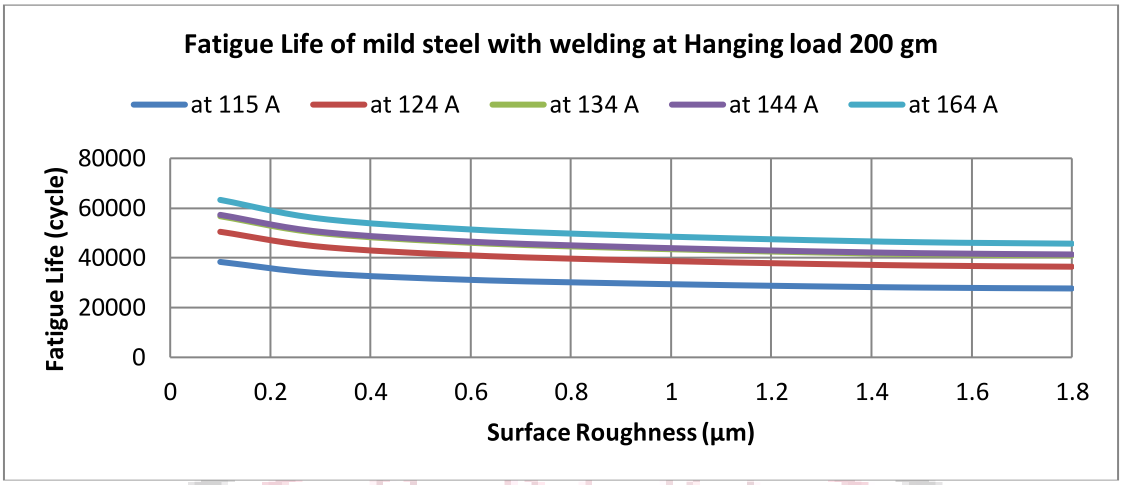

**Figure 16 Fatigue Life of mild steel with welding at hanging load 200 gm**

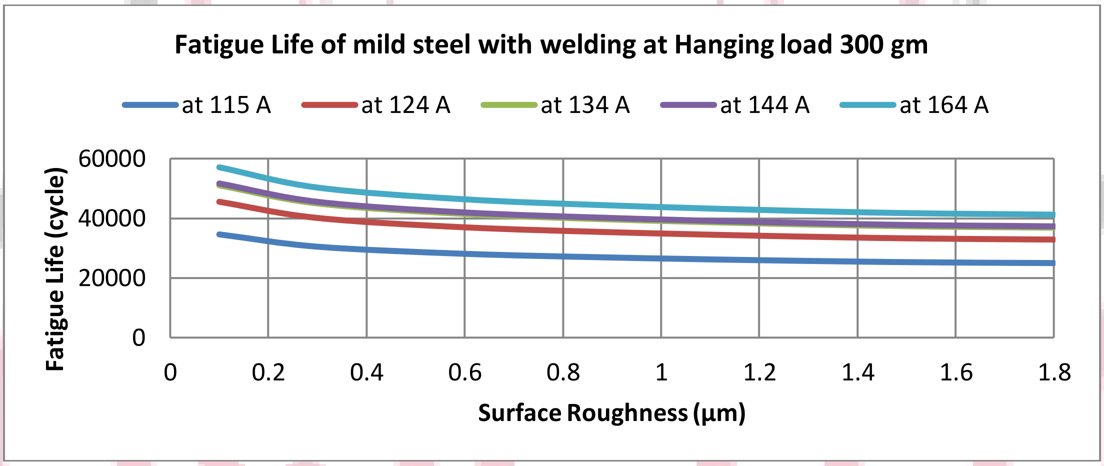

**Figure 17 Fatigue Life of Mild steel with welding at hanging load 300 gm**

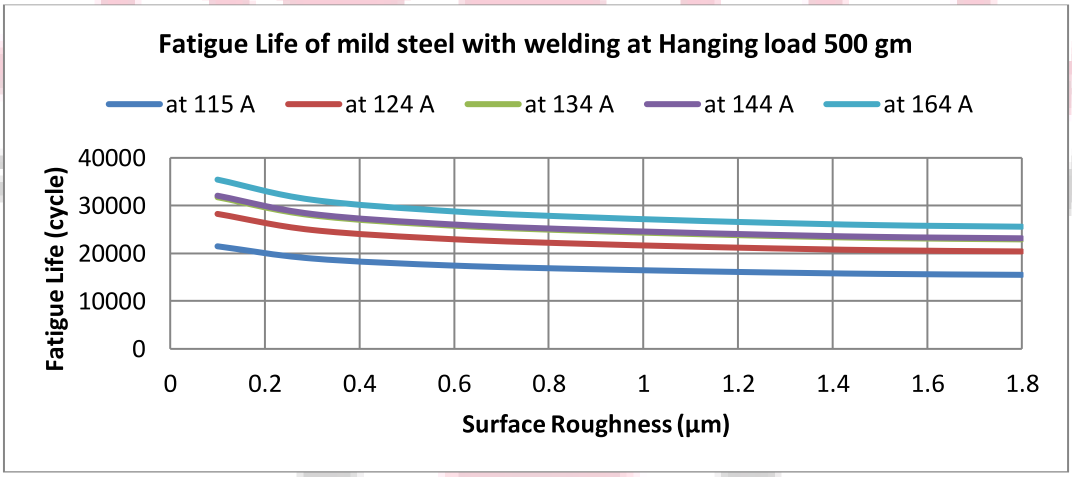

**Figure 18 Fatigue Life of Mild steel with welding at hanging load 500 gm**

From the above results it has been observed that the fatigue life of a material is affected by various factors such as surface roughness and hanging load applied on the fatigue testing. As the surface roughness increases and hanging load increases, the fatigue life of the material decreases. Understanding these factors can help in designing materials and components that can handle cyclic loading conditions and have a longer fatigue life and also the higher welding current and lower surface roughness values gives the maximum fatigue life.

## V. CONCLUSION

In conclusion, fatigue analysis has been a widely studied field that has yielded a wealth of theoretical and practical data. Mild steel, due to its affordability, durability, and other beneficial properties, has become a popular alloy in many industries. Welding techniques such as hybrid friction stir welding have been developed to improve efficiency and quality. Surface roughness has been identified as a key factor affecting the fatigue life of materials, and the study of the effects of varying surface roughness and hanging load on the fatigue life of mild steel has provided valuable insights. Overall, this research provides important information that can help engineers and manufacturers make informed decisions when selecting materials and designing structures to withstand the stresses of cyclic loading.

### *Conclusion for fatigue life test of mild steel without welding*

The following inferences about the fatigue life test of mild steel under various surface roughness and hanging load conditions without welding may be made based on the research study:

1. Surface roughness is a critical factor affecting the fatigue life of mild steel, with the maximum fatigue life observed at the smallest surface roughness of 0.1 µm, and the minimum fatigue life observed at the largest surface roughness of 1.8 µm.
2. Hanging load is also a significant factor affecting the fatigue life of mild steel, with the maximum fatigue life observed at the lowest hanging load of 200 gm, and the minimum fatigue life observed at the highest hanging load of 500 gm.
3. The highest fatigue life is observed at 164A with a value of 105742 cycles, while the lowest is observed at 144A with a value of 40718 cycles.
4. Mild steel's fatigue life enhances when the welding current is increased from 115A to 164A, with the maximum fatigue life rising from 67444 cycles to 105742 cycles.
5. The fatigue life of mild steel decreases as the hanging load increases and surface roughness increases.
6. The results of the fatigue life test might be utilised for determining the optimal hanging load and surface roughness for specific applications of mild steel, which can improve its durability and reliability.

### *Conclusion for fatigue life test of mild steel with welding*

Conclusions regarding fatigue life test of mild steel with different levels of surface roughness, welding current, and hanging load:

1. The mild steel’s fatigue life gets affected by the level of surface roughness, welding current, and hanging load applied during the fatigue testing.
2. As the welding current increases from 115 A to 164 A, the material’s fatigue life increases, indicating that higher welding current values give a better fatigue life.
3. The minimum fatigue life values are observed at 1.8 µm surface roughness and 115 A welding current, while the maximum values are observed at 0.1 µm surface roughness and 164 A welding current. This suggests that lower surface roughness values give a better fatigue life.
4. The material’s fatigue life decreases as the hanging load increases, indicating that higher hanging loads reduce the material's fatigue life.
5. Their fatigue life and potential to handle cyclic loading conditions can be improved by designing materials and components with reduced surface roughness values and higher welding current.

Overall, this study provides insightful information about the variables that affect mild steel's fatigue life and may be used to guide the design of materials and components for increased durability and dependability.

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