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Electroplating Jig Design for Mild Steel Nut for Cobalt Alloy Plating

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Abstract
This partly ongoing research focuses on designing a stainless-steel jig holder for varied sizes of mild steel nuts for cobalt alloy plating, scaled to industry-level requirements for field testing. The chosen type of electroplating jig is rack plating. The modelling and analysis of the design were done using SolidWorks software, which included 3D design and finite element analysis. The result shows the strength of the jig holder is reliable for nut sizes ranging from M8 to M16. In conclusion, the jig holder performance has been successfully optimized based on the material and design chosen for its simulation.

Keywords: Cobalt-Alloy Plating; Electroplating; Modelling; Finite Element Analysis

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1.0 Introduction

Electroplating, also known as electrodeposition, necessitates the immersion of a cathode and anode in an electrolyte. The metal salts in the electrolyte are reduced to the electrolyte-cathode interface and the plate to the cathode as current is supplied to the anode. The most common application of electroplating is to change the surface characteristics of a workpiece (Rajan, et al., 2022). The deposition of metal coatings connected to the workpiece may alter physical qualities such as strength, wear and abrasion tolerance, resistance to ambient conditions such as temperature extremes, and impact (Zhou, et al., 2018). Because of the outstanding mechanical and physical properties of electroplated Cu, copper electroplating is the most frequent and widely utilized plating method in the industry. Numerous plating systems, such as alkaline cyanide and pyrophosphate complex ion systems and acid sulphate and fluoborite simple ion systems, have been investigated and shown to be viable for commercial Cu electrodeposition. Some electroplating systems use a shielding plate to regulate the electrical potential distribution of the substrate to conduct the plating process evenly on the substrate (Taylor & Inman, 2018). The shielding plate is located between the anode and the substrate and contains a hole that allows current to travel from the anode to the substrate. When regulating the electric potential distribution, the shielding plate must be extremely near to the substrate (Murray, 2017). As a result, the substrate holder does not dispose of a shielding plate that is extremely close to the substrate holder and serves no use.

The process of applying a metal covering to a conducting surface is known as plating. However, there are several more uses, including corrosion protection, radiation shielding, paint adhesion, and many others. There are a couple of alternative plating methods that may be useful as well. Specific forms of electroplating include copper plating, silver plating, and chromium plating (Toifur et al., 2018). Electroplating

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allows producers to use low-cost metals like steel or zinc for most of the component and then add additional metals on the outside to improve the product's beauty, safety, and other attributes. The surface might be made of metal or plastic. There are several types of electroplating is commonly used in the industry, which is barrel plating and rack plating. Mass plating, also known as barrel plating, is a plating used extensively in mass production (Khan, et al., 2020). The barrel plating approach entails putting the objects in a non-conductive barrel-shaped cage. The fact that the various components establish bipolar contact with one another is a crucial feature of the barrel plating process, resulting in enhanced plating efficiency. Due to the high degree of surface contact between the components, barrel plating is not recommended when technical or aesthetic finishes are desired. Rack plating is the inverse of barrel plating (Singleton, 1999). Rack plating is excellent for the processing of specific deposits and is used for large, complicated, or fragile components. During the rack plating method, the components are hung on a "rack" that is then immersed in the plating solution. To attach the components and provide the essential electrical contact, metal hooks or bands are used. Rack plating is typically more costly than barrel plating since it requires more effort (McCormick et al., 1986). However, the biggest problem with rack plating is that direct connection to the parts on the rack causes dispensing performance to be impaired due to high and low current density areas between the parts and the rack. Parts mounted on a rack often have poor solution movement, which is important to control thicknesses, and are more vulnerable to rinsing and drying stains.

In short, the primary aim of the plating jig is to keep the component in the most advantageous position for exposure to the plating current that flows from the anode. It is well known that the arrangement and structure of the components in both the vertical and the horizontal directions is extremely necessary if there is to be fair uniformity of the deposit. Therefore, a custom-made jig holder is necessary for the electrodeposition method using cobalt alloy plating to be performed optimally at an industrial scale. In this research study, a sturdy industrial scaled plating jig for mild steel nut will be designed using SolidWorks. The designed plating jig will have the dual function of holding the samples providing electrical contact. The concept design will go through Finite Element Analysis (FEA) to evaluate its stress and deformation. The value of stress and deformation can be used to predict its performance in field testing. The best concept design will be used in the fabrication of the jig holder made from stainless steel due to good corrosion resistance.

2.0 Literature Review

Plating is the process of attaching a metal coating to a conducting surface. Plating can take place with individual metals or in different combinations (alloys), which can add value to the electroplating process (Zhou et al., 2018). Some of the most often used metals for electroplating are copper, zinc, tin, nickel, gold, silver and palladium. When deciding on the best electroplating material for the application, price, substrate composition, and desired outcome are all important considerations. An electric current is used to dissolve metal in the electroplating process and deposit it on a surface. The procedure employs four key components.

1. Anode: The metal that will create the plating is the anode, or positively charged electrode, in the circuit.
2. Cathode: The portion that must be coated in the electroplating circuit is the cathode. It is also known as the substrate. This component serves as the circuit's negatively charged anode.
3. Solution: In an electrolytic solution, the electrodepositing process occurs. To assist the passage of electricity, this solution contains one or more metal salts, often copper sulphate.
4. Power source: A power source is used to add current to the circuit. This power source introduces electricity into the system by passing a current through the anode.

Electroplating enables manufacturers to utilize low-cost metals such as steel or zinc for most of the components and then put other metals on the outer to allow for the product's aesthetic, safety, and other qualities. The surface might be composed of metal or plastic. Mass plating, also known as barrel plating, is a type of plating that is widely employed in mass manufacturing. The barrel plating method includes placing the objects in a barrel-shaped cage composed of non-conductive material. The cage is then immersed in a tank holding the proper chemical solution, and the plating operation begins with a gentle tumbling movement (Dusek et al., 2018). A critical aspect of the barrel plating process is that the various parts make bipolar contact with one another, resulting in increased plating efficiency. However, due of the high degree of surface contact between the components, barrel plating is typically not suggested when technical or decorative finishes are required (Singleton, 1999).

Meanwhile, rack plating technique is ideal for the processing of selected deposits and is utilized for big, complex, or delicate components. The components are suspended on a "rack" that is subsequently submerged in the plating solution during the rack plating procedure. Metal hooks or bands are utilized to secure the components and create the necessary electrical contact. Rack plating is more expensive than barrel plating since it is more labor-intensive (Heimke, 2007). Racks can be constructed for a single item or thousands of pieces; they can be as little as a textbook or as large as a garage door. The rack method can plate curves and complex forms more effectively, in addition to providing better protection against component damage. It has become the chosen finish in industries that need a prominent level of quality, such as military and defense, automotive, medical, and electronics (McCormick et al., 1986). The two most frequent materials used to make plating rack tips are phosphorous bronze and stainless-steel tips in both gravity and spring form. Stainless steel has been popular as a tip material in recent years, thanks to the employment of patented nitric or muriatic acid stripping solutions. The use of phosphorous bronze in such strips would cause the tip to melt too soon. It is important to remember that phosphorous bronze has a larger current carrying capacity and should be utilized when current is a factor.

3.0 Methodology

In this work, SolidWorks software has been used to create, analyse, and optimise a jig holder for the electroplating process. Several designs and materials have been considered before the final material and jig design was chosen based on certain factors such as temperature sustainability, coating material, and type and quantity of the product to be electroplated.

The rack plating type was created with a specific purpose in mind that based on the intended output for plating, a mild steel nut. Several key design aspects, such as plating tip, design dimensions, and material choices were highlighted. This is because all the parameters will indirectly influence the performance of the electroplating process. Besides that, the parameters (materials properties) such as mass (kg), volume of bodies (m^3), density (kg/m^3), weight (N), yield and tensile strength (N/m^2) were used in analyzing the performance of jig holder. These parameters were used to obtain the stress analysis and factor of safety result, which are more focusing on the performance of sample handler or holder as electroplating jig. The set parameter values used in the SolidWorks software design analysis were gathered and tabulated in Table 1 and Table 2 below.

Table 1: Solid Body Parameters

Solid Part Parameters	Description
Mass	0.00346246 kg
Volume	4.32807e-07 m^3
Density	8000 kg/m^3
Weight	0.0339321 N

Table 2: Material Properties Parameters

Material Properties Parameters	Description
Name	AISI 347 Annealed Stainless Steel
Yield Strength	2.75e+08 N/m^2
Tensile Strength	6.55e+08 N/m^2

The sample holder was tested by five different weight and diameter size of hexagon mild steel nut, which is M8, M10, M12, M14, and M16. All the sizes and weight were referred to the ISO 4032 and DIN 934, which is the standard that covers the requirements for hexagon nuts ranging from M1 to M160. It is allocated to either product grade A (up to M16 size) or product B (for sizes above M16). Table 3 below shows the weight of the sample nuts test that has been calculated by following the ISO chart. The objective to calculate the weight of all the nut samples is to identify force load carrying in the sample holder. Despite analyse the carrying load in the sample holder, stress analysis for the result also can be generated by using the weight of the sample.

Table 3: Weight of Sample (Nut)

Sample Nut Size (mm)	Weight (N)
M8	0.05102
M10	0.113796
M12	0.169713
M14	0.24525
M16	0.326673

For stress and factor of safety analysis of the sample holder design, AISI 347 Annealed Stainless Steel (SS) has been set as the predetermined material of choice. Besides that, the fixed point on the sample holder has also been predetermined before the simulation process. Fig. 1 shows the fixed geometry of the part, which is located at the endpoint of the sample holder. Then, the next step is identifying the location of the load force at the part tested. Fig. 2 shows the actual location of the sample when it located at the sample holder which is in the centre of the hook. The ultimate step in the preparing session before the simulation starts is the set the loads at the force load location based on the weight of the sample nut tested. Other than that, other parameters including solid bodies parameter, material selection properties and the weight of sample that will be tested for the analysis will be calculated by the SolidWorks software.

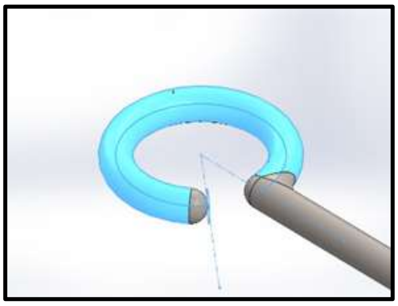

Fig. 1: Fixed Geometry.

Fig. 2: Force load location (z-axis)

Von mises stress analysis is conducted in the project to analyse the rupture stress. Von Mises stress is a value that is used to determine whether a material will yield or fracture. The von Mises stress equation is illustrated below.

$$\sigma = \sqrt{0.5\left[\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + \left(\sigma_z - \sigma_x\right)^2\right]} + \sqrt{3\left(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2\right.} \qquad (1)$$

4.0 Findings

Fig. 3 below shows the final design of the plating rack that has been made by using SolidWorks software.

Fig.3: Design of jig holder.

The dimensions of the idea design above are appropriate for plating tanks of size 43 x 17 x 34.5 inches (l x w x h). Furthermore, the material used for the jig holder design is stainless steel due to a variety of features, including excellent electrical conductivity and corrosion resistance. The plating points serve two functions: they retain the samples, and they provide electrical contact. The grip for the whole body is connected using an M8 hexagon bolt and nut. It is due to the practical concept design, which allows for changing body height and simple unracking.

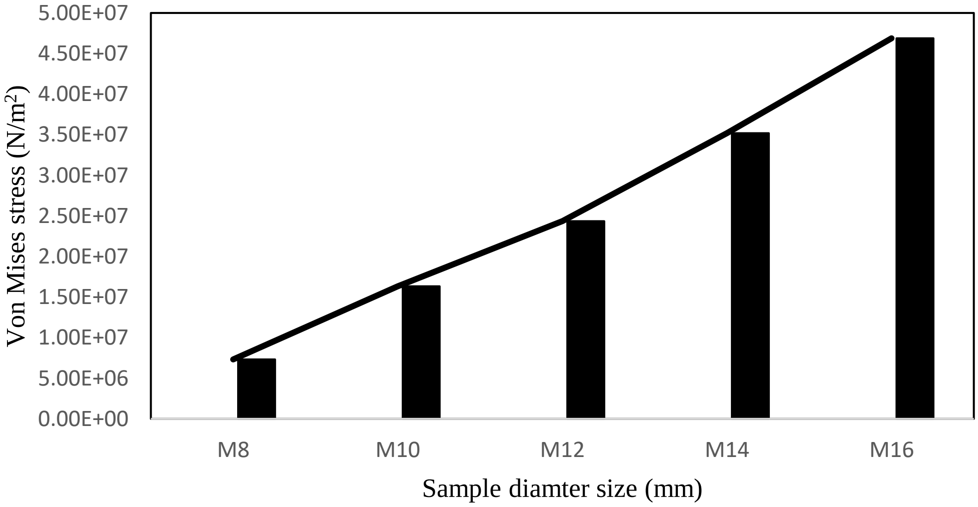

Fig. 4: von Mises stress graph of sample holder part.

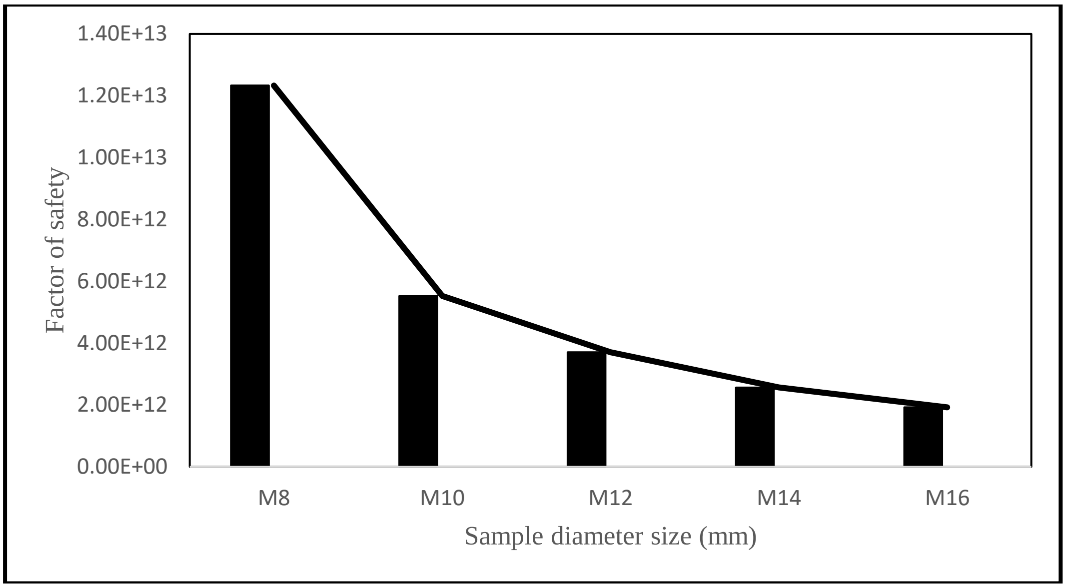

Fig. 5: Factor of safety graph of sample holder part.

Based on the result shown in Fig. 4, an increasing pattern of the von Mises stress analysis was observed. The highest von Mises stress value was recorded at M16 hexagon bolt sample with $4.688e^{+07}$ N/m^{2}. While the lowest value of von Mises stress, which is $7.322e^{+06}$ N/m^{2} were recorded for M8 size hexagon nut sample. It shows that the bigger size and more force loaded applying to the sample holder part will give higher results for the von Mises stress analysis. While the findings are opposite for the factor of safety analysis as shown in Fig. 5. The graph shows a decreasing pattern from M8 to M16 sample nut. The highest value of factor of safety recorded at M8 with $1.233e^{+13}$. Then the value goes decrease until $1.925e^{+12}$ was highlighted at M16 hexagon sample nut. It clearly shows that the sample holder part has more value of factor of safety when less force of load applied to the part, which is M8 sample with 0.051012N.

<u>M8 analysis</u>

Fig. 6 illustrate the response of sample holder response with the von Mises stress analysis when M8 sample nut applied to the part. The colour chart on the left side of the figure represented the result of von Mises stress analysis from the minimum value to the maximum value. The minimum value recorded for the analysis is $2.231e^{-05}$ N/m^{2} and its shows by the dark blue indicator, while the highest value of von Mises is $7.322e^{+06}$ N/m^{2} by using an orange colour indicator. Assume from the figure, the maximum von Mises result shows in the figure, the dark green region, is $4.393e^{+06}$ to $5.125e^{+06}$ N/m^{2,} respectively. Based on the result for M8, it clearly shows that M8 sample hexagon nut does not has high-stress analysis for the sample holder parts for the design.

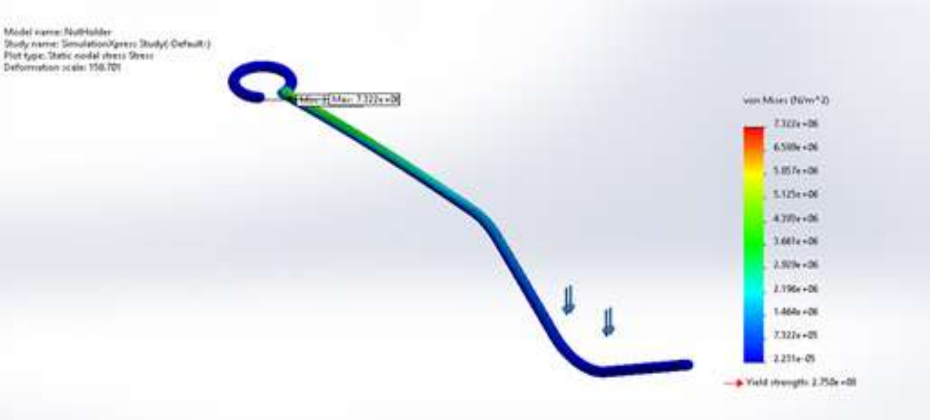

Fig. 6: von Mises stress analysis of sample holder part attached with M8 sample nut.

M10 analysis

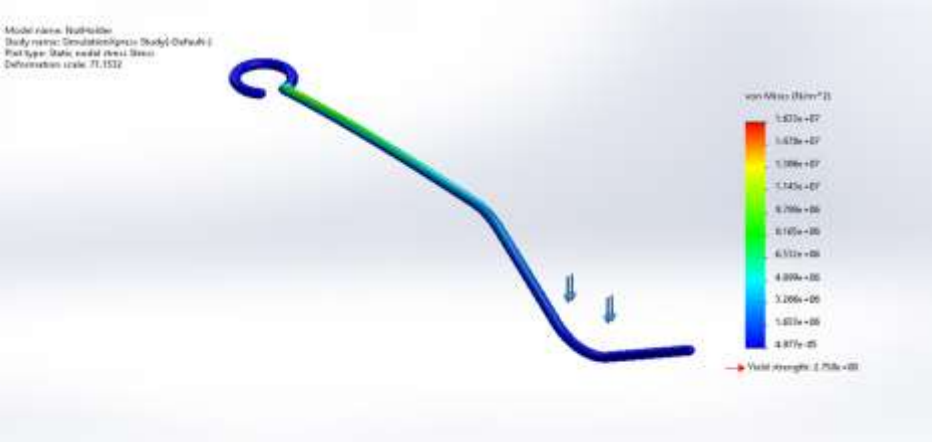

Fig. 7: von Mises stress analysis of sample holder part attached with M10 sample nut.

Fig. 7 shows the von Mises stress analysis response to the sample holder part when M10 sample size with 0.113796 N force load is applied. By analysing the von Mises stress analysis colour chart on the figure, the dark blue region indicated the minimum value of stress, with 4.977e^{-05} N/m^2, while the highest stress with the red region is 1.633e^{+07} N/m^2. This result clearly shows that the value of von Mises stress is increasing compared to the M8 value.

M12 analysis

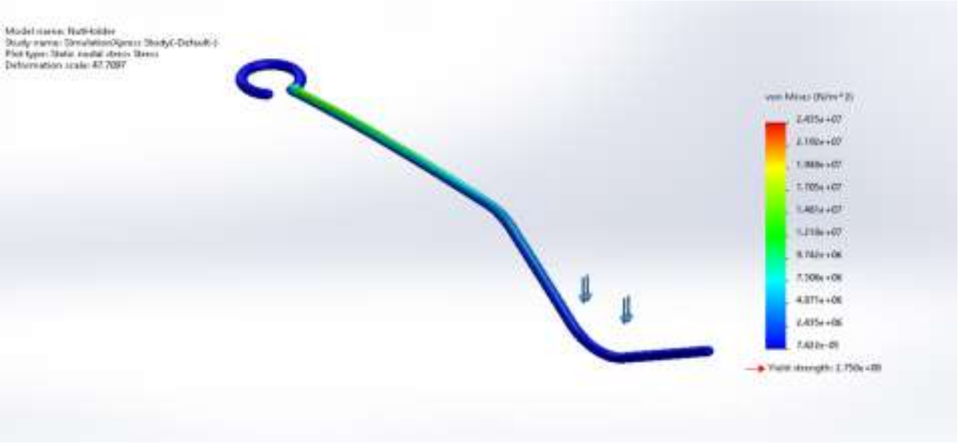

Fig. 8: von Mises stress analysis of sample holder part attached with M12 sample nut.

Meanwhile, Fig. 8 illustrates the von Mises stress analysis response of sample holder with M12 sample hexagon nut applied. By rough observation, the green region in the part produced higher values with 1.461e+07 N/m2, compared to M8 and M10 samples previously. Simultaneously, the higher value was recorded in M12 von Mises stress analysis was 2.435e+07 N/m2, while the lowest is 7.422e-05 N/m2. It also can say that the value of analysis based on the force load applied and material selection of the part, which is AISI 347 Annealed Stainless Steel.

M14 analysis

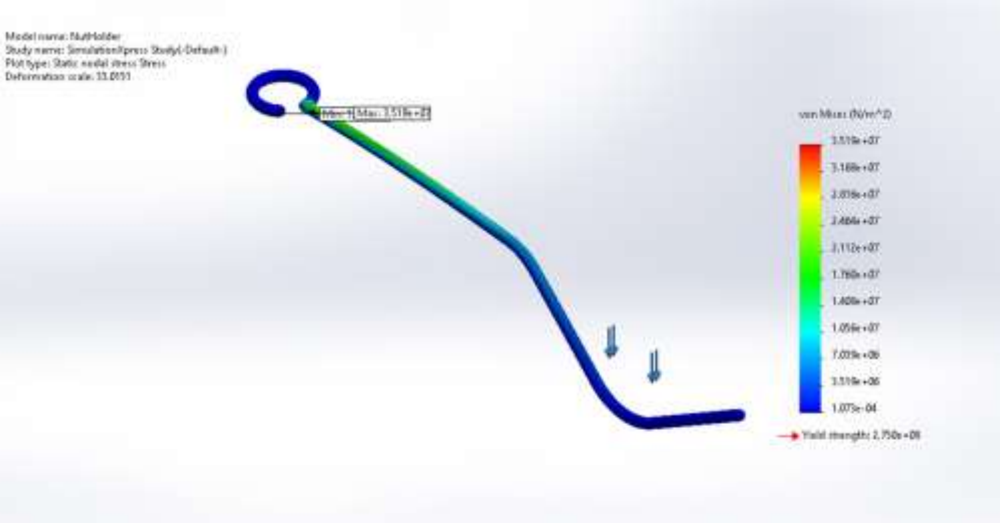

Fig. 9: von Mises stress analysis of sample holder part attached with M14 sample nut.

Fig. 9 above exemplify the response analysis on the sample holder part with 0.24525N force load applied to it. At the same time, the factor involved in this result is the material selection with 2.75e+08 N/m^2 value of yield strength, which produced by Annealed Stainless Steel properties. From the colour chart, the minimum value recorded is 1.073e-04N/m^2 with blue as an indicator. The maximum value of von Mises stress is 3.519e+07 N/m^2, with red as its indicator. The minimum value of stress observes at the end of the sample holder because the part is in blue.

M16 analysis

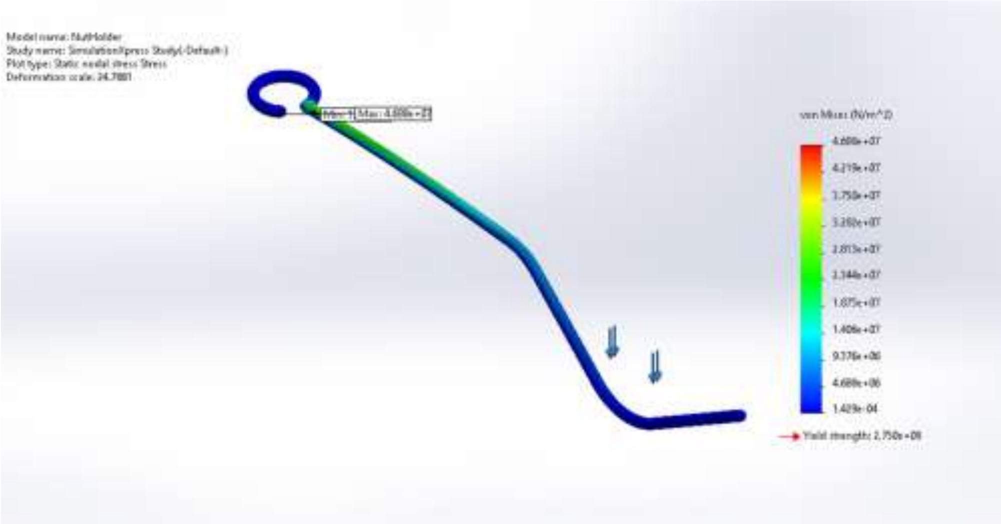

Fig. 10: M16 analysis sample holder part.

In addition, Fig. 10 shows the response von Mises stress analysis and colour chart indicator for the relationship of minimum to maximum value stress recorded in the sample holder part. From this, it can be finalized that the value of von Mises stress ranging from 1.429e-04 to 4.688e+07N/m^2. It was also observed that higher force load applied to the part, will produce a higher von Mises stress result. As been noticed, the value of von Mises stress is increasing compared to the previous sample and it clearly shows in the graph in Fig. 5. It can be deduced that the M16 sample hexagon nut with 0.326673N load is suitable for the sample holder design.

5.0 Conclusion & Recommendations

The analysis and value of von Mises stress and factor of safety with Annealed Stainless-Steel showed that a higher force load applied to the sample holder part will produce a higher value of von Mises stress and lowest value of factor of safety. The factor involved in the result analysis is due to the material of choice's yield strength and tensile strength. Overall, the result shows the reliability of the jig holder in providing its function for the nut size ranging from M8 to M16. Thus, the respective design of the jig holder can be used in future work on the electroplating process for nut samples within this size range.

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