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Design Optimization of Saddle Support for The High-Capacity Pressure Vessel Using Finite Element Analysis

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Abstract: Saddle support is used to hold a horizontal high-pressure vessel in its desired location. Fabrication of saddle regularly supports by referring to the existing code and standard in the code of ASME Code of Section (VII), Division 1 and Division 2 (Boiler and Pressure Vessel Code). This project optimizes the saddle-support structure for a horizontal pressure vessel used in the upstream operation and searches for the saddle-support requirement to enhance its safety factor. First, the existing design of the saddle is gathered from the worldwide source from Design Hub. The finite element analysis method (FEM) is used to analyze the design. Redesign 3D model of the saddle is constructed using SOLIDWORKS 2017 software. Redesign model with a different number of ribs below the saddle-support of horizontal pressure vessel, 2, 4, and 6 ribs. The analysis results are then obtained after meshing the software model using SOLIDWORKS 2017 and testing for static analysis with materials selection. Optimized design develops before in the static loading analysis lives predicted to increase from its original design. Optimized model of saddle support simulated by von mises stresses in the application. Several materials selected for the materials optimization process, such as alloy steel, 1023 carbon steel sheet, and AISI 347 annealed stainless steel was applied to saddle-support with 6 ribs. The force load was fixed to 100,000 N, which is 10 tons. The optimization result was excellent: all the redesign models with new materials passed and safe as per the von mises stress criteria. The optimized design can embrace the load by referring to this factor. Furthermore, the corrosion issue is also considered in the research, including preventing corrosion.

Keywords: Saddle support, Redesign, Optimization

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1. Introduction

Saddle support is the standard support used for horizontal pressure vessels. It is generally attached to the pressure vessel by welding on the surface of the cylindrical vessel. Saddle support is generally mounted on a base such as a cement floor or connected to a frame. For offshore usage, the critical issue of saddle support is that it is often exposed to acidic conditions, such as seawater, which can cause severe corrosion problems. It is often influenced by noise caused by other machinery from its surroundings and much further from ocean waves. To concentrate on corrosion, the design process itself did grant the saddle-support a longer life cycle [1].

Two symmetrically positioned saddle supports support horizontal cylindric pressure vessels. The stresses generated by internal pressure in the vessel trigger stress in the pressure vessel [2]. Its steel is used in the oil and gas, chemical, and power generation industries. It can be tested to meet stated requirements. Adequate formability is also a characteristic of ASTM A516 steels.

There are two different impacts on the vessel while there are supports. Firstly, it interferes with the vessel's usual expansion due to internal pressure or shifts in temperature. Secondly, the concentrated support reaction causes strongly focused tension in the support area [3]. The most important factor influencing its selection for a specific application is the corrosion resistance of one material. Finite Element Analysis (FEA) has become extremely common in recent years. It is now the foundation for a multibillion-dollar industry per year. ASTM A516 is the standard for the arrangement of steels used to manufacture commercial pressure vessels and boilers [4].

2. Methodology

2.1 Flowchart

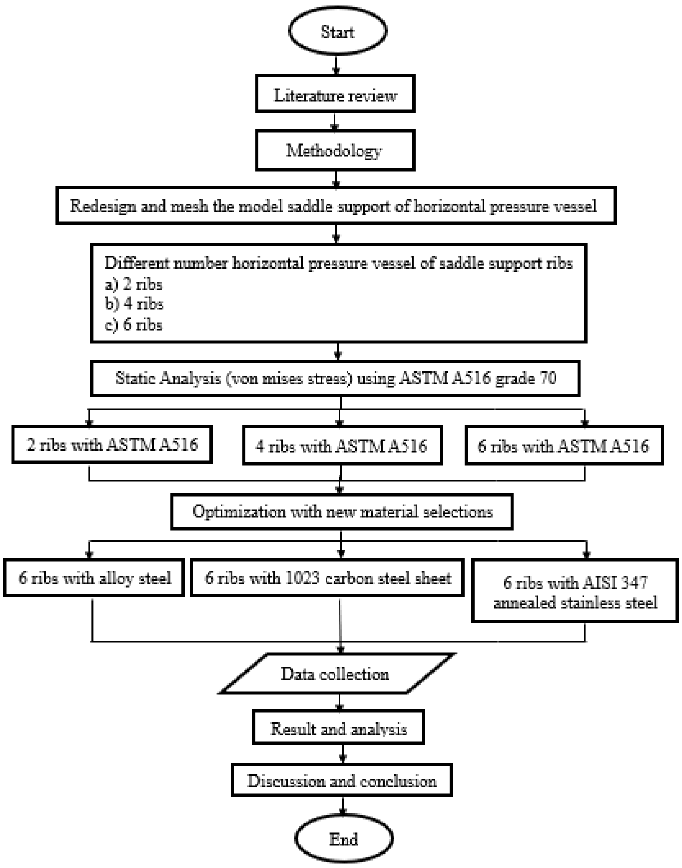

Figure 1: List of material

2.2 Preliminary Process of FEA

The literature review details how the saddle supports of horizontal pressure vessels were made, the material used, and the software used to build the saddle supports. In this thesis, there are two essential steps in redesign and optimization the saddle support. The original design with two ribs redesigns into 4 and 6 ribs with the same dimensions at the preliminary stage. Next, three new materials were selected to be optimized with three designs with a different number of ribs. Additionally, redesign the model to varying the number of ribs, which is 4 and 6 ribs. The original design consists of 2 ribs; meanwhile, the model and decided to redesign, which consists of 2 different saddles with the idea of a redesign, adds a different number of ribs. The first one consists of 4 ribs in total, while for another one, the saddle-support of saddle supports consists of 6 ribs. The original design only got two ribs and the additional ribs for the redesign idea to make the saddle-support more durable and more vital to accommodate the load from the horizontal pressure vessel itself. The meshing is generated for all designs in SolidWorks.

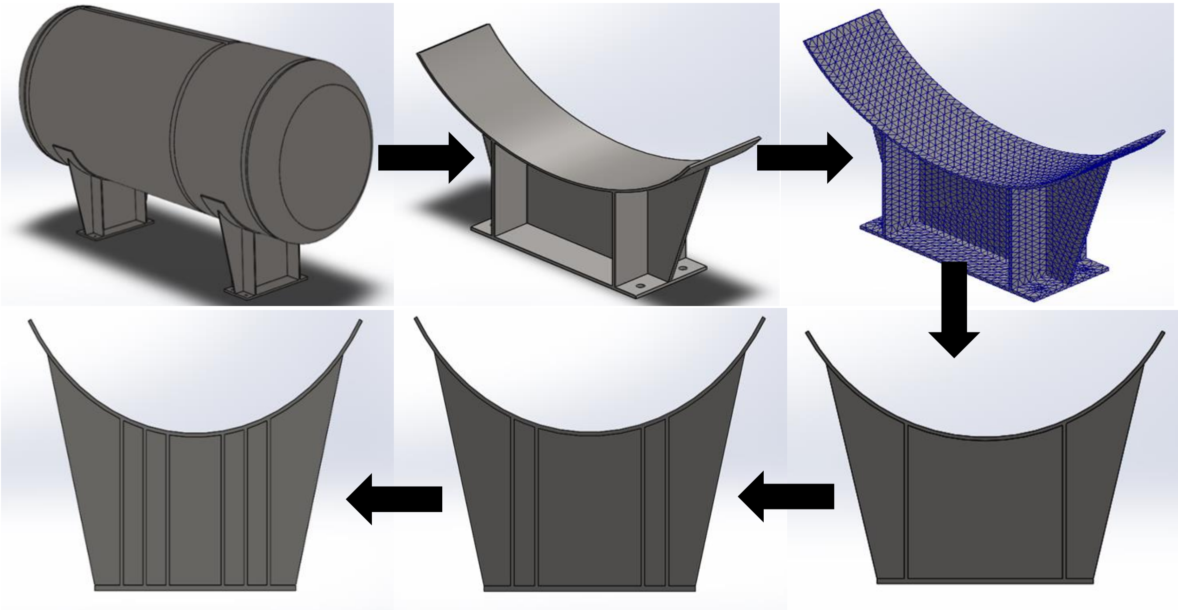

Figure 2: Preliminary process of FEA

2.3 Von Mises Stress

Von mises are used to define failure in ductile materials, while maximum principal stress (normal pressure) is used to determine failure in Brittle materials. Using SolidWorks application, maximum von mises stress and most critical points are established. Various optimization approaches are evaluated to reduce the saddle-support overall stress for the horizontal pressure vessels [5]. All saddle-support models completed the von mises stress, including the optimization version.

2.3 Material applied on saddle support of horizontal pressure vessel

The material was used on the saddle-support, which is the standard material for both saddle support and horizontal pressure vessel, ASTM A516 grade 70. These redesign models were tested with three different materials to be tested on fixed load, which 10 tons used for the static analysis, von mises stress. This saddle vessel applied ASTM A516 grade 70, carbon steel as the primary material for saddle vessel components in the whole industry, considered by ASME.

2.4 Optimization process with new materials

Optimization was done to determine another material that can be more durable than ASTM A516 for the redesigned model of saddle support of horizontal pressure vessel. To add other ribs under the saddle-support with a different number, 4 and 6 ribs, automatically redesigned the original design into a new shape and tested the new layout with other materials.

2.4.1 Alloy Steel for Rib Saddle Support

This material was selected for saddle-support optimization because of its numerous advantages such as more excellent hardenability, less distortion and cracking, tremendous stress relief at given hardness. Von misses stress analysis to test the materials with a redesigned model, six ribs saddle support of horizontal pressure vessel.

2.4.2 1023 Carbon Steel Sheet for 6 Saddle Support

The overall tensile and yield strength of a carbon steel piece differs enormously based on the steel and other production factors' carbon content. High carbon steel has a much higher tensile strength, which is suitable for saddle support to know the von mises stress of the redesigned model of 6 ribs.

2.4.3 AISI 347 Annealed Stainless Steel

Stainless steels are high-alloy steels with high corrosion resistance due to large quantities of chromium compared with other steels. This material has so many advantages to the saddle-support, such as resistance to corrosion, resistance to oxidation, the beauty of appearance, and high strength with low weight.

3. Results and Discussion

3.1 Load for saddle support of horizontal pressure vessel

This simulation shows the stress tensor on the part, deformation of the region, displacement, and the maximum forces that the saddle-support part can handle. In this research, the horizontal pressure vessel's load force was fixed at 200,000 N (20 Ton force) for two saddle support, and decided to divide the weight into 100,000 N (10 Ton) for each saddle. That kind of value exists because the simulation shows the actual value the saddle-support can hold the force from the top precisely at 100,000 N (10 ton). The simulation at high risk if the value exceeded 110,000 N.

3.2 Static Analysis Result

3.2.1 Original design with 2 ribs with ASTM A516

Von misses stress for the minimum show that the value is 4.955e+01 N/m^2 and for the maximum stress is 2.831e+08 N/m^2. The yield strength for ASTM A516 results showed that the ASTM A516 is low than the alloy steel itself, 2.620e+08 N/m^2. The result in figure 3.1 showed that the material is not suitable for two ribs saddle support.

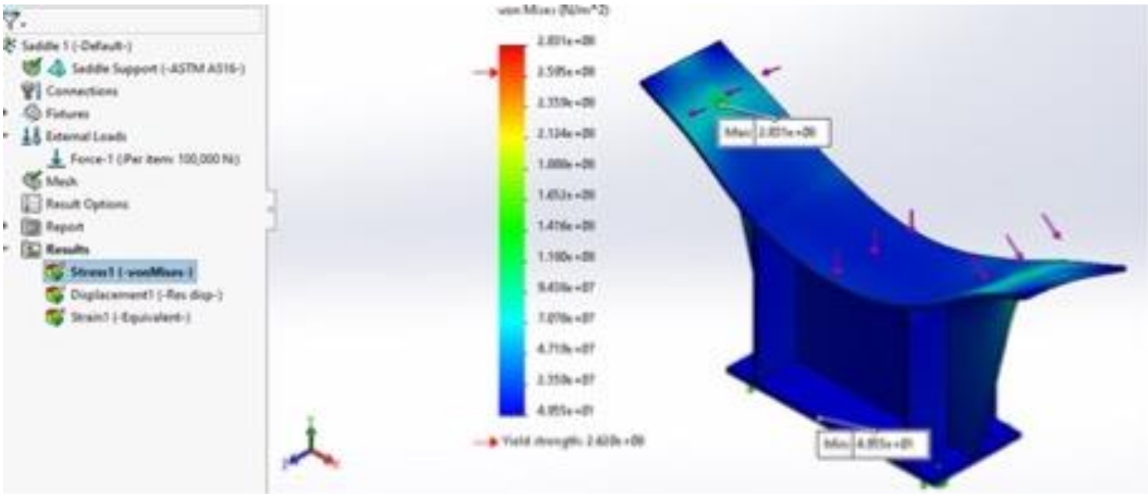

Figure 3: ASTM A516 applied on 2 rib saddle support

3.2.2 4 Rib Saddle-Support with ASTM A516

The value of the yield strength of the saddle-support is 2.620e+08 N/m². The minimum value of von mises stress is 3.508e+01N/m², while the maximum value is 2.700e+08N/m². The maximum value surpasses the value of yield strength, which is the breaking point near the maximum stress. This redesigned model at high risk of the criteria of the research, as shown in Figure 4 below.

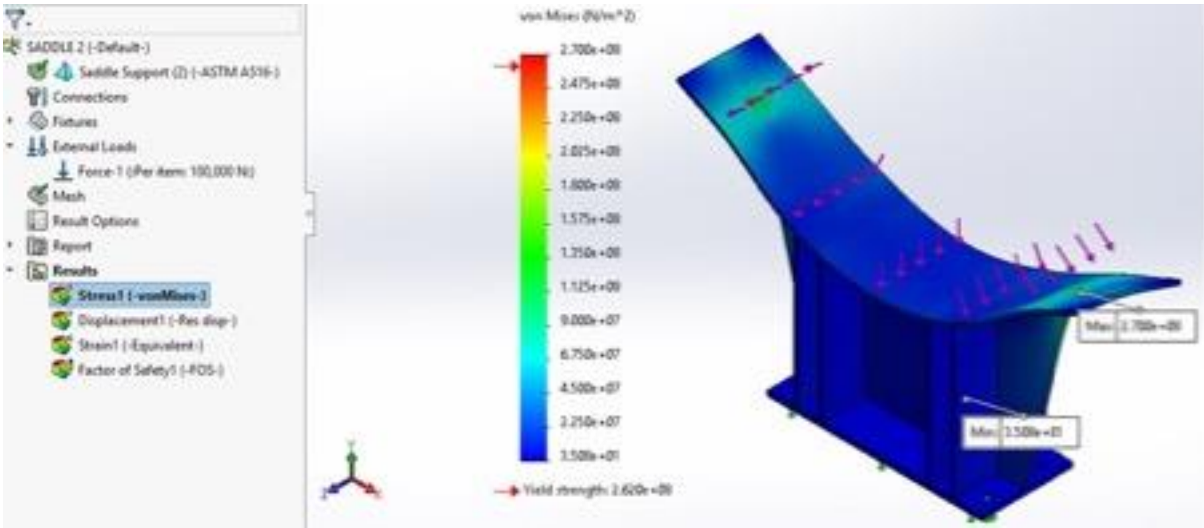

Figure 4: ASTM A516 applied on 4 ribs saddle support

3.2.3 6 Ribs Saddle Support with ASTM A516

The value of the yield strength is 2.620e+08 N/m². The von mises stress of the minimum value is 2.656e+02 N/m², while the maximum value is 2.605e+08 N/m². This material is suitable when the saddle-support got six ribs applied to the design. The maximum stress value can prove this passed result is below the yield strength itself, as Figure 5 below.

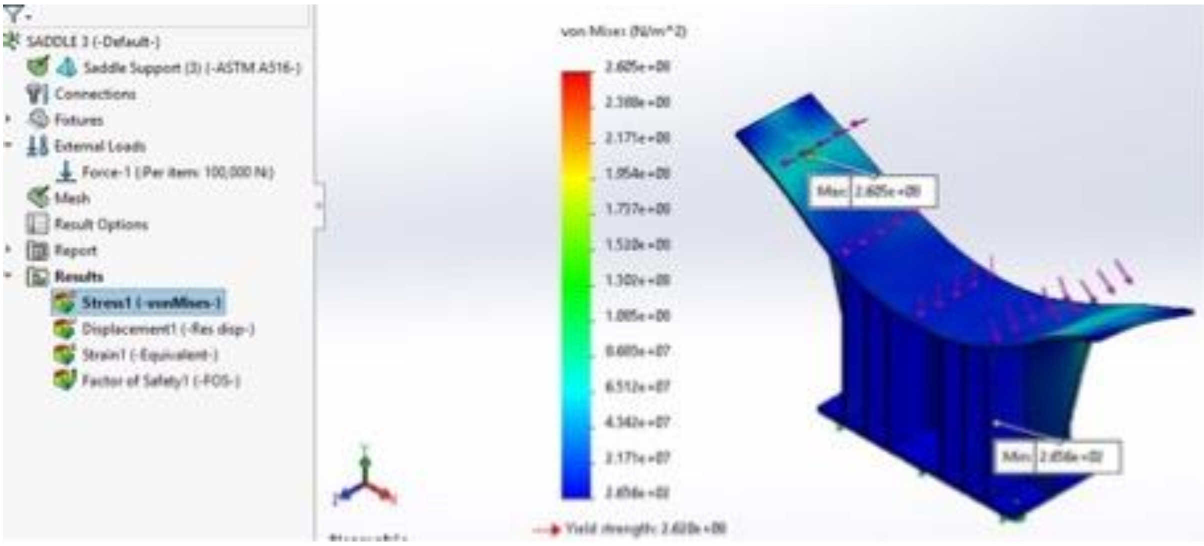

Figure 5: ASTM A516 applied on 6 ribs saddle support

The graph as Figure 6 below showed that, for the overall analysis above for using ASTM A516 as material for three designs with a different number of ribs, six ribs with ASTM A516 material proven are more suitable for six ribs type saddle support of horizontal pressure vessel. Additionally, for all results given above, the lowest stress calculated for six ribs saddle-support, which is only 260.5 MPa compared to other results 283.1 MPa and 270.0 MPa. The passed redesigned model, which six ribs saddle-support chose, is the best among the three designs above.

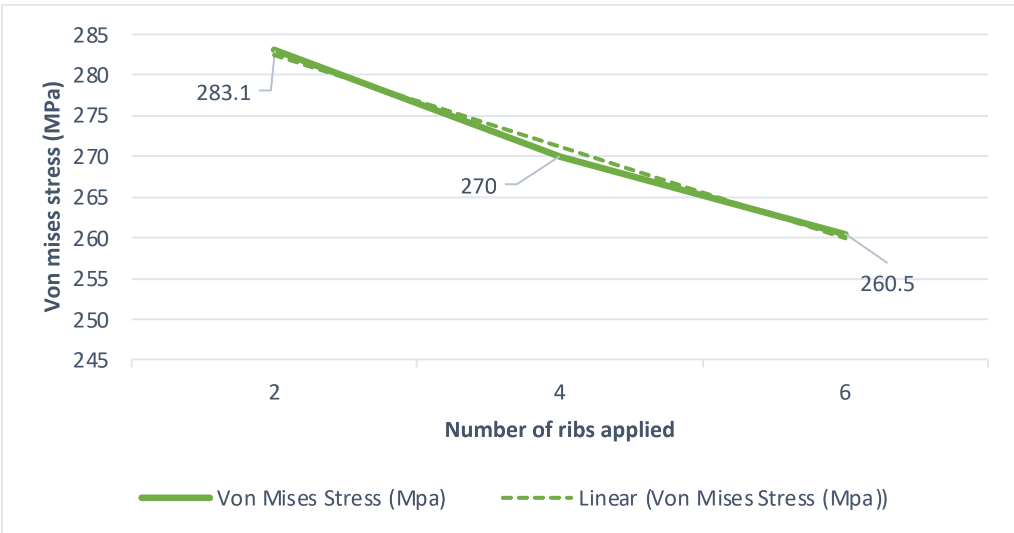

Figure 6: Graph of the saddle-support with ASTM A516 material

3.3 Optimization with materials selection

3.3.1 Ribs saddle-support with alloy steel

The result showed that the von mises stress for a maximum of this design can hold 2.851e+08 N/m², and for minimum, this actual original design can pass 3.885e+0.1 N/m². The value of yield strength, which is 6.20422e+08 N/m², also showed in figure 3.4 below. The saddle support is made up of alloy steel, and so corrosion allowance is considered. Awareness of the yield strength is critical when constructing materials since it typically reflects the upper limit of the load that can be added. Yield intensity is essential for regulating the manufacturing techniques of many materials, such as welding, rolling, or pressing.

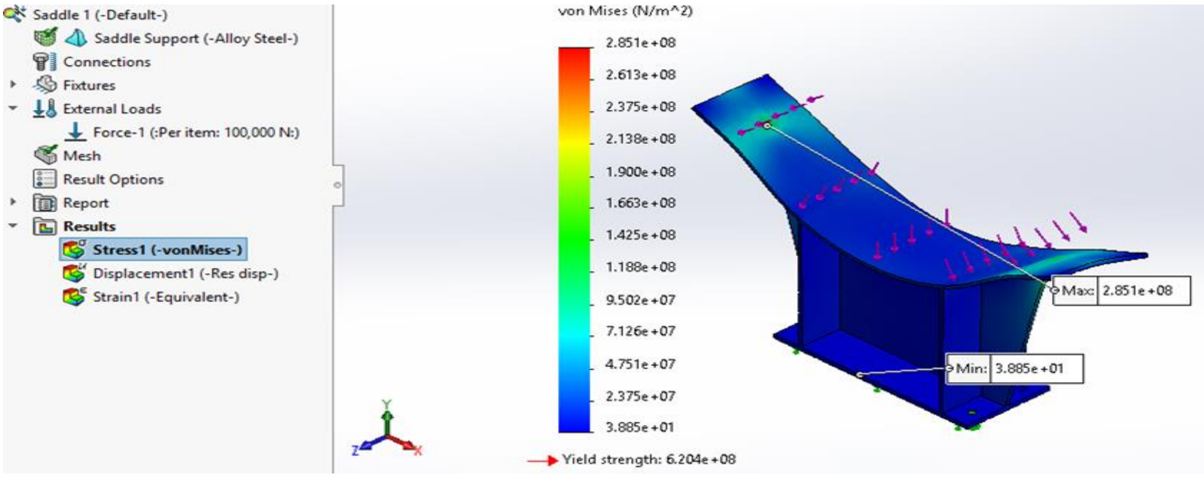

Figure 7: Original Design With 2 Ribs and Alloy Steel

3.3.2 6 Ribs saddle-support with 1023 carbon steel

The result showed that the von mises stress for the minimum 3.126e+01 N/m² and the maximum stress is 2.712e+08 N/m². The yield strength result showed that this material with six ribs could yield at 2.827e+08 N/m². The value of the maximum is surpassing the value of yield strength. The redesigned model with this material is suitable and already passed the simulation phase, as Figure 8.

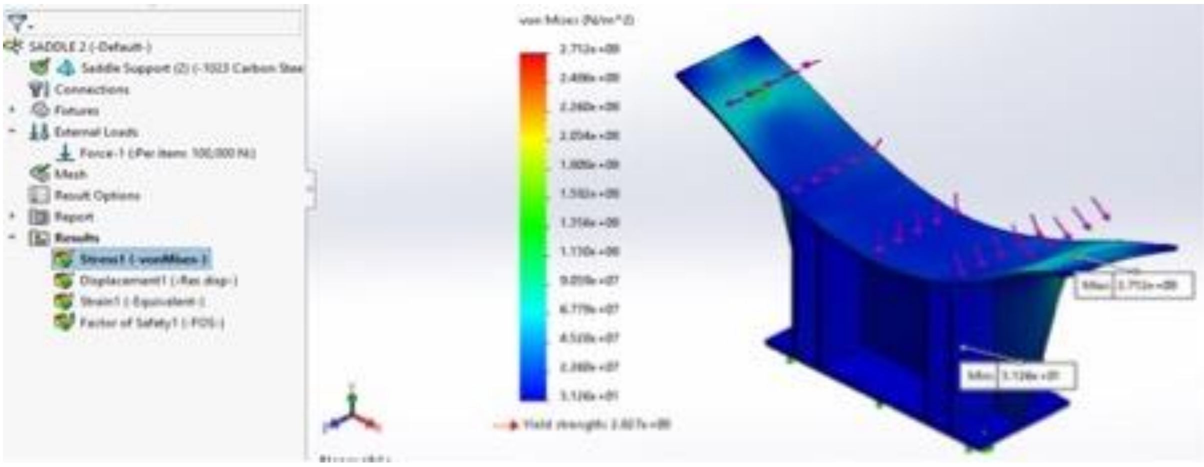

Figure 8: 1023 carbon Steel on 4 ribs saddle support

3.3.3 6 ribs saddle-support with AISI 347 annealed stainless steel

The simulation result of the minimum von mises stresses value is 3.739e+02N/m², while the maximum von mises stress is 2.633e+08N/m². However, the yield strength value is 2.750e+08 N/m², which is higher than the maximum von mises stress itself. This result showed that this redesigned model with six ribs with annealed stainless steel passed the optimization criteria. The saddle support is made up of stainless steel, and so no corrosion allowance is considered.

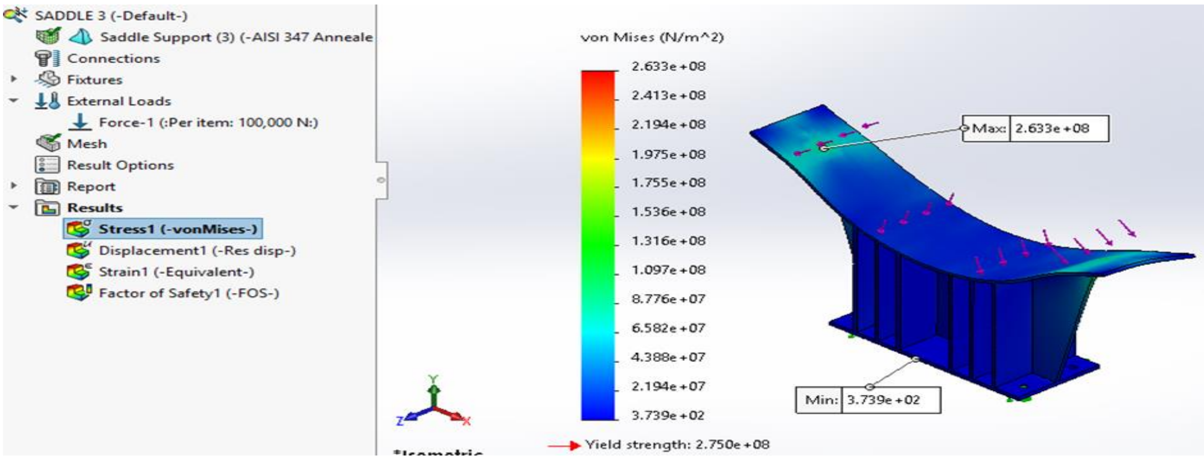

Figure 9: AISI 347 annealed stainless steel for 6 ribs

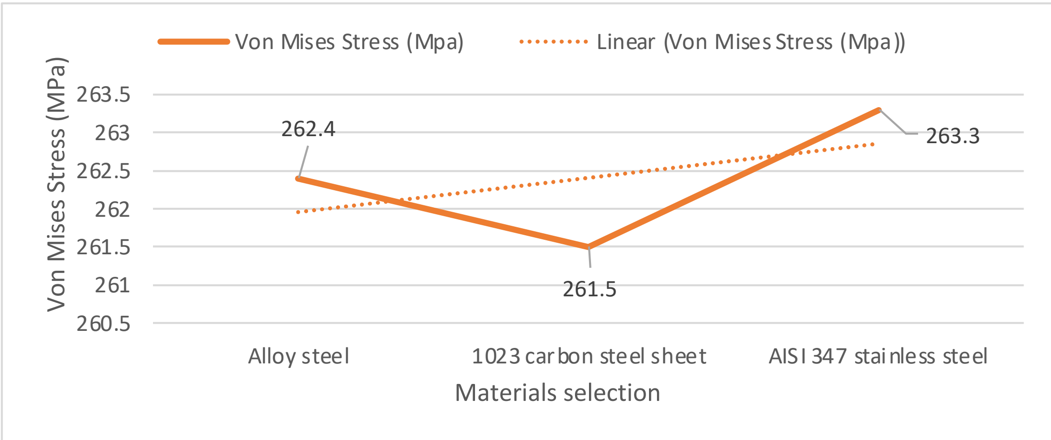

Figure 10: Graph of saddle support with different materials selection

The graph above showed that for overall analysis for six ribs saddle-support above for using other materials, the lowest among the above materials selected is 261.5 MPa by 1023 carbon steel sheet material. Carbon steel material chosen for less stress applied on six ribs saddle support.

3.4 Overall Result of the Simulation

Table 1: Comparison of stresses at a varying number of ribs

Material	Number of ribs	Stress Calculated	Ton Force
ASTM A516	2 (Original model saddle-support)	283.1 MPa	10 tonf
ASTM A516	4 (Redesign model saddle-support)	270.0 MPa	10 tonf
ASTM A516	6 (Redesign model saddle-support)	260.5 MPa	10 tonf
Alloy steel	6 (Redesign model saddle-support)	262.4 MPa	10 tonf
1023 carbon steel sheet	4 (Redesign model saddle-support)	261.2 MPa	10 tonf
AISI 347 Stainless steel	6 (Redesign model saddle-support)	263.3 MPa	10 tonf

After making changes in rib number and calculating von mises stress shown in table 4.7, it is observed that stresses induced in 2, 4, and 6 ribs are 283.1 MPa, 270.0 MPa, 260.5 MPa, respectively. However, for the optimization by materials selection, alloy steel, 1023 carbon steel sheet, and AISI 347 stainless steel are 285.1 MPa. 271.2 MPa, and 263.3 MPa, respectively. So, it has been found that the optimization by materials can improve the stress that saddle-support can accommodate. From the von mises stress result, it has been found that the saddle-support using ASTM A516, which is 2 and 4 ribs, is not safe and at high risk of the criteria. But the other saddle-support using six ribs are passed and secure as per the von mises stress measures. The optimization process, which is alloy steel, 1023 carbon steel sheet, 201 stainless steels, has been found that all three optimizations are under the safe limit as per the von mises stress.

3.5 Cost Analysis of Material Selection for Optimization

Table 2: Estimated cost for materials selection

Materials (per kg) (India)	Price in INR (per Kg)	Price in RM (per Kg)	Mass for 1 saddle support (Kg)	Estimated cost for 2 saddle support
ASTM A516	Rs. 58	RM 3.19	173.373	RM 1,106.12
Alloy steel	Rs. 160	RM 8.80	171.15	RM 3,012.24
1023 carbon steel	Rs. 45.47	Rm 2.50	174.662	RM 873.31
AISI 347	Rs. 150	RM8.24	177.818	RM2,930.44

3.6 Corrosion Problem

Corrosion risks of the oil sector are always problematic to the company involve in this industry. Corrosion affects every aspect of exploration and production, from offshore rigs to casing. This study is also intended to identify corrosiveness that can have an impact on saddle-support life. The seawater, which is the problem this study wants to focus on, involves oil, gas, and refining equipment corrosion. To choose the materials successfully and design, produce, and use metal structures for the full economic life of the installations and protection during oil and gas operations, corrosion's concepts must be recognized [6].

Figure 11: Corrosion

Table 3: Comparison of four materials about corrosion and other criteria

Materials	Strength	Ductility	Toughness	Cost	Corrosion Resistance
ASTM A516	✓	✓	✓	✓✓	✓
Alloy Steel	✓✓	✓	✓	✓✓✓	✓
1023 Carbon Steel sheet	✓✓	✕	✓	✓	✕✕
AISI 347 Stainless steel	✓	✓	✓	✓✓✓	✓✓✓

There are many criteria for each material simulated in this study, the most acceptable materials that can be accepted is AISI 347 stainless steel. As a result, stated in table 4.7, the most less stress applied on horizontal saddle support is 1023 carbon steel. Even though the output goes to 1023 carbon steel sheet, another criterion also must be considered in this study. The corrosion issue must also be striving for solution according to the choices of materials simulated in this study. As we know about stainless got the best solution to cut off the corrosion issue. But the price also plays a significant part, even for saddle support. The longer life of saddle support can live, the longer lifespan saddle-support will be. The cost expensively high for stainless steel material compared to carbon steel or other material listed.

The ASTM A516 currently the primary material for saddle-support, even for the pressure vessel itself. For those designers for the future, ASTM A516 can be changed to stainless steel for a better saddle-support design. Although the cost must be the main problem for stainless steel, it will bring numerous advantages to the saddle-support itself, cutting the cost of repair or maintenance regarding corrosion to the saddle support. Stainless steel provides many benefits for architectural/ornamental metal users. The key advantages include its high resistance to corrosion that allows it to be used in rigorous environments. It is fire and heat resistance that helps it to resist scaling and maintain high-temperature power.

The primary option for applications that need strict hygiene control, such as hospitals, kitchens, and other food processing plants, is the hygienic, non-porous surface coupled with the simple cleaning capacity of stainless. For most architectural metal applications, aesthetic appearance offers a modern and desirable appearance. Its vivid and easy-to-maintain body makes it an easy choice for applications always needing an appealing surface. Its weight benefit strength allows it to be used with reduced material thickness over traditional grades, resulting in cost savings. Simple production due to the use of advanced steel-making techniques that will enable stainless steel to be cut, machined, processed, welded, and shaped as quickly as conventional steels. Long-term value, owing to its long usable life period, also offers the least costly material choice

3.8 Corrosion Coating for Saddle Support

Coating a metal surface with paint or enamel establishes a bond between the metal and the environment's moisture. The sacrificial coating is the practice of coating a metal surface with another metal that is more likely to be oxidized. Additionally, the use of any coating depends on the fact that it is important to distinguish metal from a hostile environment. This type of solution can be used for saddle support in the future. Coating requirements that protect systems and machinery under different conditions must develop immune to gas, fuels, water, and aqueous solutions, atmosphere, soil, high temperatures, and under thermal insulation [7].

4. Conclusion

This research is mainly about redesigning the 3D horizontal pressure vessel saddle-support model geometry into a better durable specification with redesign the lower saddle-support by adding a different number of ribs such as 2, 4, and 6 in total. After done a simulation of all the designs, 6 ribs are the most successful redesign model. The finite element analysis under static and materials section for the design optimization. The von mises stress was calculated by SolidWorks application with a fixed force load at 10 tons. The most suitable material for 6 ribs saddle-support applied for future usage is AISI 347 stainless steel. The estimated cost for this material was quite high, but it is worth the price. Corrosion can be happening anywhere or anything that metal corrodes when it reacts with another substance such as oxygen, hydrogen, moisture environment, or even dirt and bacteria. Stainless steel result was low risk and recommendations to the future saddle-support designers.

Acknowledgement

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