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# A Finite Element Method Simulation for Rocket Motor Material Selection

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***Abstract*****—**This article aims to study the effect of pressure on rocket motor case by Finite Element Method simulation to select optimal material in rocket motor manufacturing process. In this study, cylindrical tubes with outside diameter of 122 mm and thickness of 3 mm are used for simulation. Defined rocket motor case materials are AISI4130, AISI1026, AISI1045, AL2024 and AL7075. Internal pressure used for the simulation is 22 MPa.

The result from Finite Element Method shows that at a pressure of 22 MPa rocket motor case produced by AISI4130, AISI1045 and AL7075 can be used. A comparison of the result between AISI4130, AISI1045 and AL7075 shows that AISI4130 has minimum principal stress and confirm the results of Finite Element Method by the used of calculation method found that, the results from Finite Element Method has good reliability.

***Keywords*****—**Rocket motor case, Finite Element Method, principal Stress.

## I. Introduction

THIS paper studies the effect of pressure on rocket motor case by Finite Element Method in various materials as a guideline for material selection in rocket motor case manufacturing. This is very important because while solid propellant is burning, the pressure inside rocket motor case increases. If the motor case is not strong enough, it can be dangerous to the worker.

This paper studies the effect of pressure on rocket motor case by Finite Element Method in various materials as a guideline for material selection in rocket motor case manufacturing. This is very important because while solid propellant is burning, the pressure inside rocket motor case increases. If the motor case is not strong enough, it can be dangerous to the worker.

In rocket motor manufacturing process, preform is imported to the flow forming process to produce the rocket motor case. After flow forming process, the rocket motor case is subjected to hydrostatic test. The motor case must be able to withstand the pressure of 22 MPa to pass strength testing standards of rocket motor case. This process is to test the strength of rocket motor case after metal forming. It is very necessary to confirm the quality of rocket motor case after forming process.

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In part of material found that, material used in rocket motor case manufacturing are not diverse. There are many different types of materials that can be used in manufacturing process but must regard to the mechanical properties of material.

In the part of analysis, finite element method is a popular method widely used. This method has advantages to research and development. It can reduce cost and time to spend in research and development process, and also help the researcher or worker to analyze or solve the complex problem.

From this concept, AISI4130, AISI1026, AISI1045, AL2024 and AL7075 are used and 22 MPa pressure is applied to internal surface to study the mechanical properties of material by Finite Element Method. Which in this study the mechanical properties of materials didn't improve. The results in this study can be use to applied in rocket motor case manufacturing.

## II. Theory and Procedure

### A. Stress in Thin-Wall Pressure Vessel [1]

A thin-wall pressure vessel is a closed container designed to hold gas or liquid inside the container. The container in this study is the rocket motor case, which similarly to the thin-wall pressure vessel. The pressure will occur in two directions which are longitudinal and circumferential. The equations of stress on a thin-wall pressure vessel in longitudinal and circumferential directions are:

$$\sigma_c = \frac{Pr}{t} \quad (1)$$

$$\sigma_l = \frac{Pr}{2t} \quad (2)$$

This equation represents a stress direction in thin-wall pressure vessel in the Fig. 1.

### B. Failure Criteria [1], [2]

The purpose of failure criteria is to predict or estimate the yield/failure of structural members subjected to states of stress. The failure criteria of material can be analyzed in two cases which are maximum principal stress and maximum shear stress.

TABLE I
SYMBOL AND UNITS

| Symbol | Commentary | Unit |
|---|---|---|
| $P$ | pressure | MPa |
| $r$ | radius | mm |
| $t$ | thickness | mm |
| $\sigma$ | stress | N/mm$^2$ |
| $c$ | circumferential | - |
| $l$ | longitudinal | - |

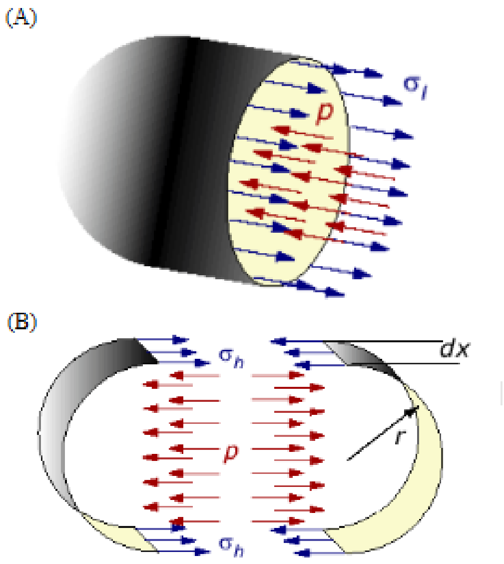


Fig. 1 Stress direction on thin-wall pressure vessel (A) longitudinal stress and (B) circumferential stress on material surface

For the purpose of this study, only the maximum principal stress is discussed because the stress on material in this paper is tension stress. The maximum principal stress theory can accurately to predict failure in tension and compression stress. This theory is used for biaxial states of stress assumed in a thin-wall pressure vessel. Whereas, the maximum shear stress theory is accurately used to predict failure in shear stress on material which does not occur on material in this paper

This theory can be illustrated graphically for the four states of biaxial stress shown in Fig. 2.

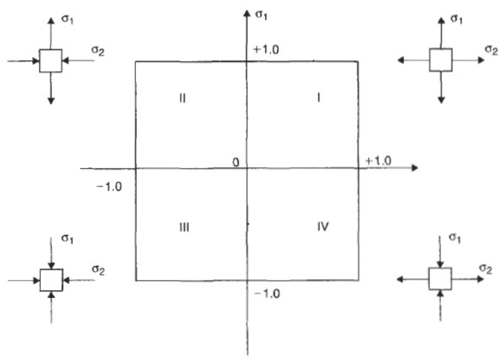


Fig. 2 Graph of maximum principal stress theory

From Fig. 2, the quadrant I and III are biaxial tension and biaxial compression. The quadrant II is tension and the quadrant IV is compression.

The failure of material occurs from the weakening of a material caused by repeatedly applied loads on material resulting in a stress on material surface. When the stress reaches a yield or failure point of materials, it results in material deformation from initial geometry.

### *C. Finite Element Analysis [3]*

The principal of finite element method begins by bringing attention to the problem domain and dividing into subsets (element) as show in Fig. 3. Then, consider each element by creating the equation of each element. The equation created is in accordance with differential equation of the problem. Afterwards, compound the equation of each element and incarnate to large equation system. After that, determine the boundary condition into the equation and analyze the problem.

Precision and accuracy of the results are according to size and number of element on material surface and also depends on the equation (interpolation functions) used in analysis.

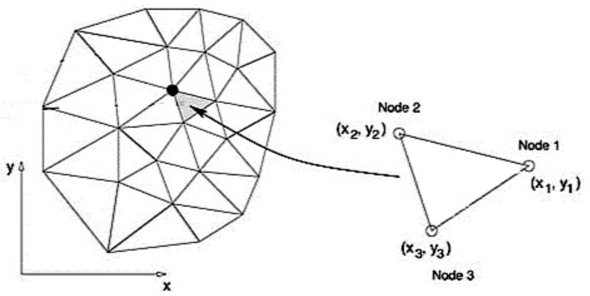


Fig. 3 Divided the problem domain into sub element to create the equation

### *D. Mechanical Properties of Materials [4], [5]*

The mechanical property of materials in this study is shown in Table II.

TABLE II
MECHANICAL PROPERTIES OF MATERIALS

| Steel type | Yield tensile stress ($N/mm^2$) | Elongation (%) |
|---|---|---|
| AISI4130 | 460 | 22.5 |
| AISI1026 | 415 | 15 |
| AISI1045 | 505 | 12 |
| AL2024 | 425 | 3 |
| AL7075 | 470 | 9 |

### *E. Rocket Motor Case Geometry and 3D Model*

In order to analyze the stress of the rocket motor case, the motor cases in this study are made from materials shown in Table II. The outside diameter of rocket motor case and its thickness are 122 and 3 mm respectively (Fig. 4).

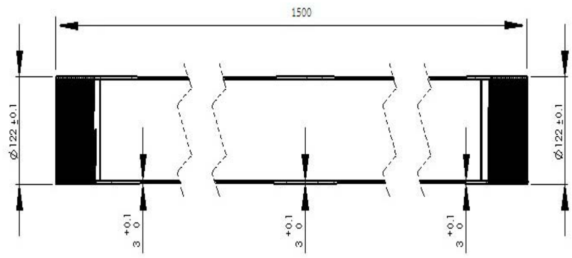


Fig. 4 Rocket motor case geometry

Create the 3D model of rocket motor case from drawing detail according to the design for analysis trend of stress on the model by Finite Element Analysis. As shown in Fig. 5.

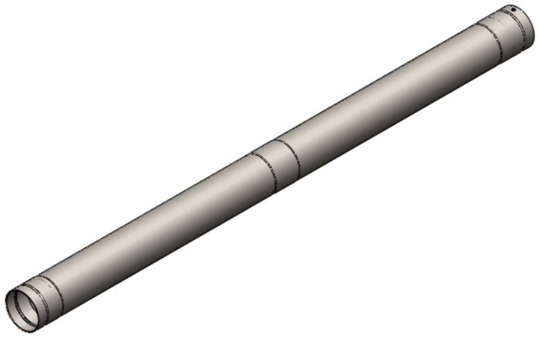

Fig. 5 3D model of rocket motor case

Observing the trend of strength by varying the mechanical properties of material but do not vary rocket motor case geometry.

*F. Boundary Conditions [6]*

The rocket motor case is fixed on two sides. The displacement of the rocket motor case is zero as shown in Fig. 6.

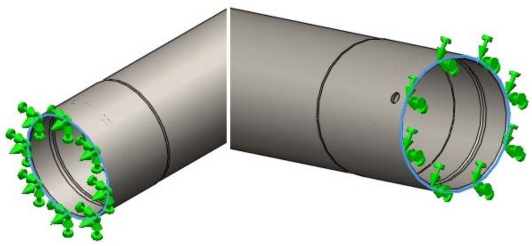

Fig. 6 Fixed on two sides of rocket motor case

In the order to carry out the finite element analysis, the boundary conditions are selected with the same conditions.

*G.Loading Condition [6]*

The load of the rocket motor case is an internal pressure at 22 MPa which is a requirement from hydrostatic test process. As shown in Fig 7.

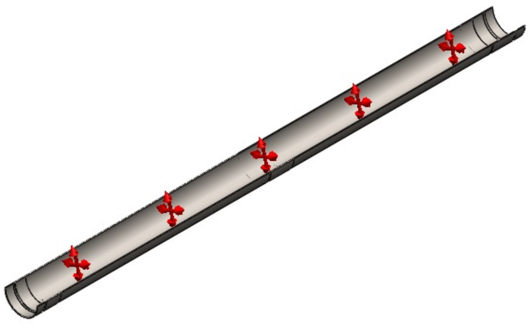

Fig. 7 Applied pressure on inner surface of rocket motor case

*H.Computing Grid [6]*

In order to calculate the stress of the rocket motor case by finite element method, the model needs to include a grid partition, which uses trigonal shapes. The grid number is 102,357 as shown in Fig. 8.

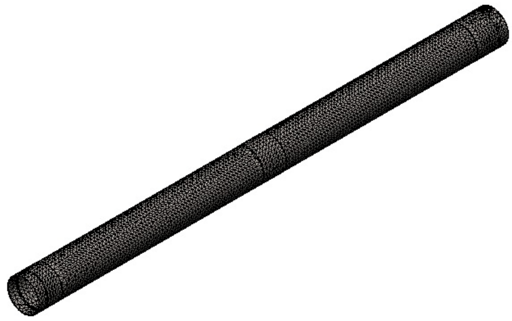

Fig. 8 Finite element grid of rocket motor case

## III. Result And Discussion

The result from finite element analysis shows the area with principal stress on surface material and its influence to the structure of the rocket motor case which is shown on Fig. 9.

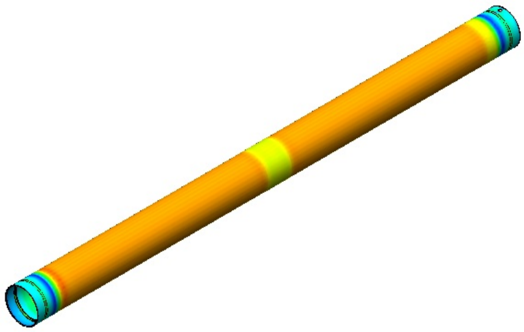

Fig. 9 Principal stress on rocket motor case

The result from Finite Element Analysis shows the relative of principal stress and materials on material surface as shown in Fig. 10.

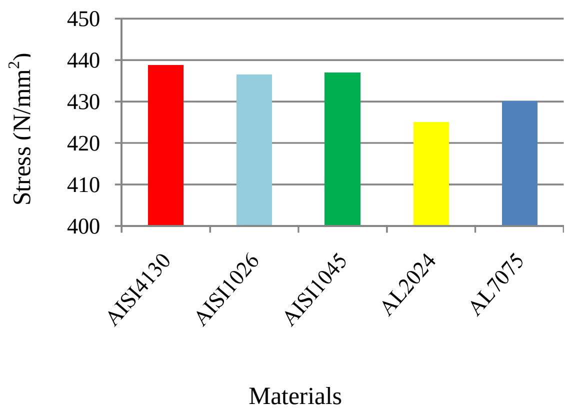


Fig. 10 The principal stress on material surface

Fig. 10 shows results of pressure simulation on rocket motor case by Finite Element Method on five materials, principal stress on inner surface of AL2024 is the lowest and AISI4130 has the highest principal stress. This represents the ability of material to receive pressure. At the same time, this ability to receive pressure in each material depends on material yield criteria (yield tensile stress) as shown in Table II.

When considering results from Finite Element Method with yield criteria (yield tensile stress) from Table II, it is found that, AISI4130, AISI1045 and AL7075 can be used in rocket motor case manufacturing because the results of principal stress from Finite Element Method of AISI4130, AISI1045 and AL7075 do not exceed the yield criteria. On the other hand, the results of AISI1026 and AL2024 exceed from yield criteria as shown in Fig. 11.

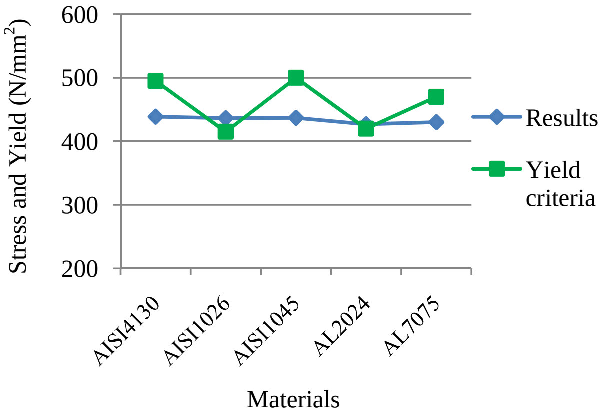


Fig. 11 The principal stress with yield criteria

Considering principal stress compared with yield criteria of AISI4130, AISI1045 and AL7075, it is found that AISI1045 has minimum principal stress (Table III)

When calculate pressure vessel from (1), it is found that, there is only little difference between the results from Finite Element Method and pressure vessel calculation (Table IV). The difference between results from Finite Element Method and pressure vessel calculation are 1.93, 2.42, 2.31, 4.47 and 3.85 percent which indicates that the result from Finite Element Method is reliable.

TABLE III
PERCENTAGE OF STRESS ON MATERIALS SURFACE

| Steel type | Percentage of stress on materials surface (%) |
|---|---|
| AISI4130 | 95.63 |
| AISI1045 | 86.53 |
| AL7075 | 90.55 |

TABLE IV
DIFFERENCE PERCENTAGE OF THE RESULTS BETWEEN FINITE ELEMENT METHOD AND PRESSURE VESSEL CALCULATION

| Steel type | Difference percentage of results (%) |
|---|---|
| AISI4130 | 1.93 |
| AISI1026 | 2.42 |
| AISI1045 | 2.31 |
| AL2024 | 4.47 |
| AL7075 | 3.85 |

## IV. CONCLUSION

The result from a study of an effect of pressure on rocket motor case by Finite Element Method on five materials found that the results on each material are slightly difference. AISI-4130 has highest principal stress and AL2024 has lowest principal stress. This result indicates the ability of materials to withstand pressure. But when compared results between Finite Element Method and yield criteria of each material found that, AISI4130, AISI1045 and AL7075 can be used in rocket motor case manufacturing. When compared between Finite Element method and calculation method to confirm the reliability of results found that, there is only slightly difference.

This article studies only Finite Element Method which could have experimental study to help confirm the results from simulation. In the future study, the process of material properties improvement can help to improve material properties which affect the quality of materials and can be study in future work.

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