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Crack Analysis of Polyoxymethylene Reinforce Glass Fibre Material on Locker Table

Ainun Nidhar[1,a] , Genia Auberta[2,b], Anissa Puspa Dewi[3,c], Ghany Heryana[4,d]

[1,2,3] Politeknik Negeri Jakarta, Prof G.A Siwabessy Kampus UI – Depok 16425, Indonesia

[4] Departemen Teknik Mesin, Fakultas Teknik,STT Wastukancana, Indonesia

[a]ainun241294@gmail.com, [b]ghany.heryana@president.ac.id

Abstrak.

Polyoxymethylene (POM) merupakan salah satu jenis thermoplastic yang sering digunakan dalam berbagai aplikasi industri karena memiliki stabilitas dimensi yang baik, tahan terhadap korosi, dan kekuatan tarik yang unggul. Namun, pada aplikasi tertentu seperti locker table, kelemahan material ini terungkap dalam kegagalan struktural. Penelitian ini menggunakan metode finite element simulation untuk menganalisis kegagalan pada locker table yang terpapar gaya pegas (helical torsion spring). Fokus utama adalah pada patahnya bagian yang terhubung dengan helical torsion spring, sebuah permasalahan umum dalam aplikasi material plastik yang mengalami beban siklik. Hasil menunjukkan bahwa patahan terjadi pada tingkat stress 121,061 MPa, melampaui nilai yield strength yang seharusnya patah pada 150 MPa. Selain itu, analisis menunjukkan tegangan Von Misses tertinggi terjadi pada tempat pegas berada, melebihi *yield strength* yang ditetapkan. Uji tarik menunjukkan efek temperatur lingkungan pada tensile strength material POM+25%GF. Solusi yang diusulkan melalui pengembangan struktur tambahan berupa rib pada produk berhasil meningkatkan kekuatan locker table terhadap beban. Penelitian ini memberikan wawasan penting dalam perbaikan desain produk untuk meminimalkan risiko kegagalan struktural pada material POM+25%GF.

Kata kunci: Desain, *Finite element, Helical torsion spring,* Meja loker, *Von misses stress*

Abstract.

Polyoxymethylene (POM) is a type of thermoplastic that is frequently used in various industrial applications due to its good dimensional stability, corrosion resistance, and superior tensile strength. However, in certain applications such as locker tables, the weakness of this material is revealed in structural failures. This research uses the finite element simulation method to analyse the failure of a locker table exposed to a helical torsion spring. The main focus was on the fracture of the part connected to the helical torsion spring, a common problem in plastic material applications subjected to cyclic loading. Results showed that the fracture occurred at a stress level of 121.061 MPa, exceeding the yield strength value that should have been broken at 150 MPa. In addition, the analysis showed that the highest Von Misses stress occurred where the spring was located, exceeding the specified yield strength. Tensile tests showed the effect of ambient temperature on the tensile strength of the POM+25%GF material. The proposed solution through the development of an additional structure in the form of ribs on the product successfully increased the strength of the locker table under load. This research provides important insights in improving product design to minimise the risk of structural failure in POM+25%GF material.

Keywords: *Design, Finite element, Helical torsion spring, Locker table, Von misses stress*

Introduction

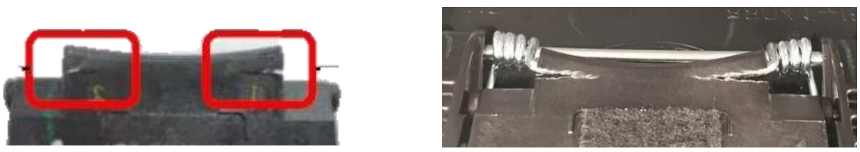
Polyoxymethylene (POM) also known as acetal, polyacetal, and polyformaldehyde is a type of thermoplastic a derivative of the semicrystalline moplastic polymer, which has a flexible main chain [1–3]. POM can be used to replace metals because it has the advantages of dimensional stability, resistance to corrosion, has a low coefficient of thermal expansion, is resistant to most chemicals and organic solvents, resistant to room temperature, and has good tensile strength with an elastic modulus of 3 GPa to 4 GPa [3,4]. POM material is commonly used in conveyor chain areas, automotive components and spring elements, but POM has shortcomings, namely weak in impact resistance and not resistant to high process temperatures [2,5].

The mechanical properties of the material are interesting, because the selection of the material will affect the mechanical load that can be hold [6]. Several studies have been conducted to improve the quality of POM with the addition of fillers such as calcium carbonate, talc, diatomite, clay, and glass fibre [2]. For the mixing of fibers in polymers will change their mechanical properties, but the properties of the composite will be strengthened depending on the number of compensation, fiber distribution and material thickness [7]. It is known that the addition of glass fiber to the injection process can strengthen POM material with the ultimate tension at reinforced 25% glass fiber (POM+25%GF) 11.8-117.1 MPa 1.7 times stronger than 15% glass fibre (POM+15%GF), the Young Modulus of POM+25%GF is 1.28 times greater [7].

One of the uses of POM+25%GF is on a locker table or folding table lock (Figure 1), with the material specifications in Table 1. Locker tables have a problem with high production defects in the form of fractures in the parts that hold helical torsion springs (Figure 2.) which are springs by generating rotational force where both ends are supported on a shaft and will decrease in diameter along with the rotation of the spring [8]. The helical torsion spring used in this case is a type of SWP-B with dimensional specifications as in Table 2, the load (force) given by the spring on the locker table, can be found through Equation 1 to Equation 4 [9].

(a) (b)

Figure 1. Locker Table (a) Front View, (b) Rear View



(a) (b)

Figure 2. (a) Fault Position on Locker Table Front View, (b) Torsion Spring Position with respect to Fault

$$\theta = \frac{M\,l}{E\,I} \quad (1)$$

It is known that :

$$l = \pi D n \;;\; I = \frac{\pi d^4}{64} \text{ dan } M = W y$$

So that :

$$\Theta = \frac{(W\,y)(\pi\,D\,n)}{E\,(\frac{\pi\,d^4}{64})}$$

$$W = \frac{\Theta\,E\,d^4}{64\,y\,D\,n} \quad (2)$$

Information:
D = Spring diameter (mm)
d = Spring material diameter (mm)
n = Number of active turns
M = Bending moment (N.mm)
E = Young's modulus (N/mm^2)
I = Moment of inertia
W = Force acting on the spring (N)
Y = Distance of the load from the spring axis (mm)
Ɵ = Total torsion angle (radians)
l = Wire length (mm)

Generally to analyze cracks and fractures of materials is using a microscope to determine the flow of polymer plastics and allow crack characteristics, the fracture mechanism is divided into Linear Elastic Fracture Mechanism (LEFM) and Non Linear Fracture Mechanism (NLFM), where in LEFM the tensile stress will increase, at the time stress increases when subjected to a sudden load, while NLFM cracks arise due to the expansion of deformation at the end of the crack before spreading [6].

Table 1. Specification of Polyoxymethylene+25%glass fibre material at 23 °C

1.	**Specification**	2.	**Value**
3.	Density	4.	1,59 g/cm^3
5.	Tensile Strenght at Break	6.	150 MPa
7.	Yeild Strengh	8.	120 MPa
9.	Elongation at Break	10.	2%
11.	Tensile Modulus	12.	9,3 GPa
13.	Flexural Strenght	14.	160 MPa
15.	Melt temperature	16.	190-220 °C
17.	Mold Temperature	18.	70-100 °C
19.	Drying Temperature	20.	100 °C
21.	Drying Temperature	22.	1-3 hours
23.	Moisture Content	24.	< 0,2%

Polymer failure can also occur because the applied stress is greater than the permissible force or the material properties not in accordance with the processing conditions so it cause the defect happen, while material fatigue can occur due to an increase in stress cycles which is the relationship between material stress and the frequency of use or operation [10].

Several studies has been found to analyze failures and cracks in POM materials on the motor body using the Scanning electron Microscope (SEM) test method, thermal analysis, injection process analysis with the results that improper process setting at the time of injection will cause a large external load on the material so that it makes the material brittle and cracked [2]. The parameters during the injection process using the Direct Fiber Feeding (DFF) technique can affect the mechanical properties of the material, when the screw is rotated at a certain turn, it will reduce the content and length of the fibers so as to affect the final tensile strength of the POM+GF material [10]. Another study analyzed the stress on the pins and disk material of the POM using the Finite Element method using ANSYS Workbench software by varying the pressure applied until the pin area experienced maximum tension, then re-designing by increasing the pin length [11].

Finite element is a method to predict or simulate the resistance of a material from force, temperature and fluid flow using software, some software that can be used for this method is ANSYS, Autodesk, and Solidwork [12]. The finite element method is used to break down a system whose behavior is unpredictable using a closed equation into smaller parts or elements whose solutions can be known or predicted [13]. In this study, the fracture analysis on the locker table, using the finite element method with Solid Work software, which is combined with other methods to determine the main cause of the fracture.

Table 2. Material Specification of Torsion Spring SWP-B

25.	**Specification**	26.	**Value**
27.	Diameter Material Spring	28.	1,5 mm
29.	Diameter Spring	30.	6,4 mm
31.	Free Arm	32.	5,25 mm
33.	Active Winding	34.	3
35.	Arm Length 1	36.	8,6 mm
37.	Arm Length 2	38.	8,9 mm

Method

The stages (Figure 3.) that are carried out to find out the cause of the locker table fracture are by validating several design data and simulating the load given, including:

3D Scanning

In this study, products that experience failure will be scanned to get product designs directly, the 3D Scanning machine used in this study is MetraSCAN with type PQCM056-1 and VXElements software.

Checking Drawings with Existing Design

This stage will compare the results of the 3D scan of the product design with the planned drawing. If the design is declared appropriate, the next step is to analyze the structural design using the Finite Element method.

Design Optimization with Finite Element

The basic steps in the Finite Element Analysis method include:

a. Definition of product type and material properties, incorporation of model geometry (meshing). This research uses Solidwork software on the simulation feature.
b. Application of loads and limitations on products
c. Next, the plotting or running stage of results.

Analysis of Von Misses Stress and Displacement Results

Von Misses stress is the force acting on the surface of an object per unit area and is measured in MPa. If the maximum stress value (von misses stress) is greater than the yield strength value, then the structure will undergo plastic deformation [14]. Meanwhile, displacement is a change in the shape of an object that is affected by force. The analysis of von misses stress and displacement in this study was carried out using SolidWorks Simulation software. Analysis in the simulation helps determine the potential for damage to the workpiece and optimize the design of the workpiece to be safer and more stable [14].

Product Re-Design

The improvement chosen in this study is to redesign the part of the product with the potential for damage because it bears the greatest load [15].

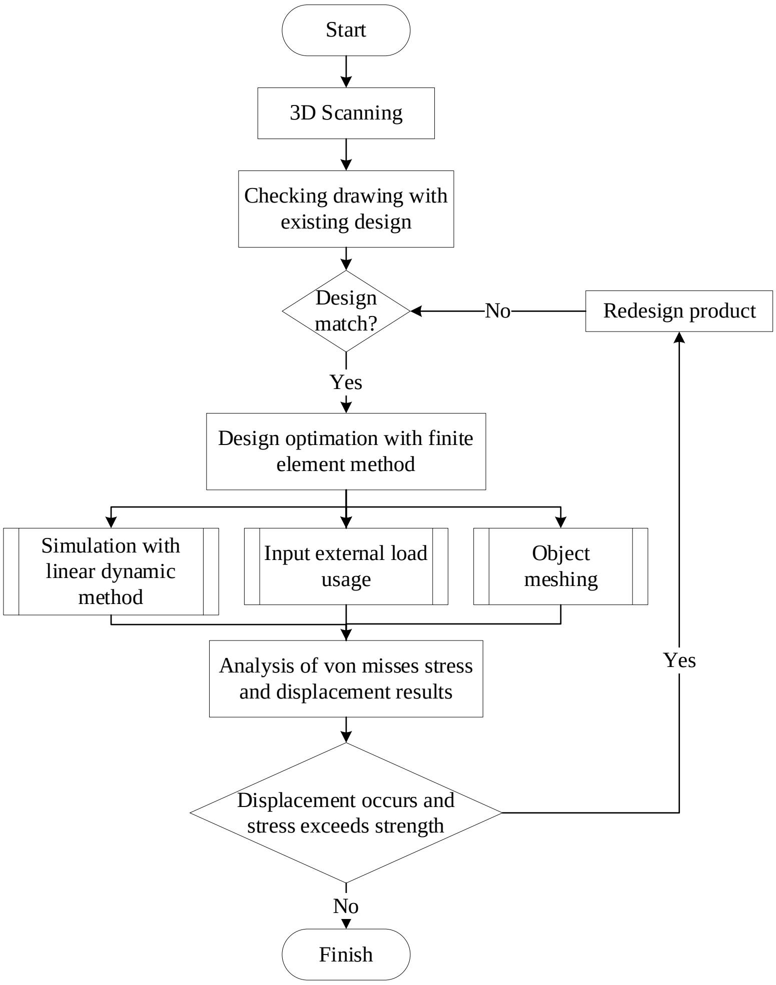
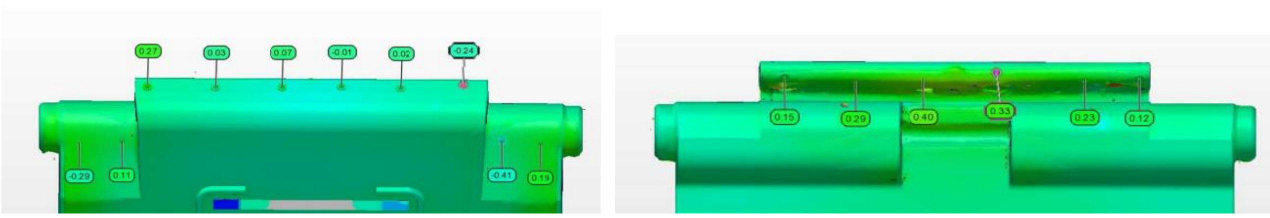


Figure 3. Research Flow Diagram

Result and Discussion

The locker table has a fracture in the part connected to the helical torsion spring (Figure 2b). From the results of 3D scanning, it was depicted that the locker table was still by the specified dimensional tolerance, which was ±0.5 mm (Figure 4.) with the largest deviation scanning result at -0.41mm. Furthermore, the torsion spring dimension validation is carried out based on the drawing with the results as shown in Table 3.



(a) (b)

Figure 4. Results of 3D Scanning Locker Table (a) Front View, (b) Rear View

Table 3. Torsion Spring Check Results based on Drawing

39.	Specifcation			40.	Sample				
				41.	1	42.	2	43.	3
44.	Diameter Material Spring (mm)	45.	1,5	46.	1,5	47.	1,5	48.	1,5
49.	Diameter Spring (mm)	50.	6,4±0,3	51.	6,46	52.	6,36	53.	6,43
54.	Free Angle (°)	55.	70±3	56.	71,55	57.	71,55	58.	71,55
59.	Total Panjang (mm)	60.	53,5 ±1	61.	53,11	62.	53,58	63.	54,1
64.	Bending Length (mm)	65.	37 ±0,5	66.	37,13	67.	37,12	68.	36,93

In the simulation of the finite element, it is necessary to know in advance the load spring force applied to the locker table using Equation (2) with the force distribution in Figure 5. It is known that the material diameter of the spring (D) is 1.5 mm, the diameter of the spring (D) is 6.4 mm, the number of active turns is 3, the load distance from the spring sumbe (y) is 8.9 mm, the modulus of elasticity (E) is 206,000 N/mm^2, and the spring torsion angle (ϴ) is 110° (1.9 radians), so that:

$$W = \frac{\Theta\ E\ d^4}{64\ y\ D\ n}$$

$$W = \frac{(1{,}9)\ (206.000)\ (1{,}5)^4}{(64)\ (8{,}9)\ (6{,}4)\ (3)}\ , W = 181{,}182\ N$$

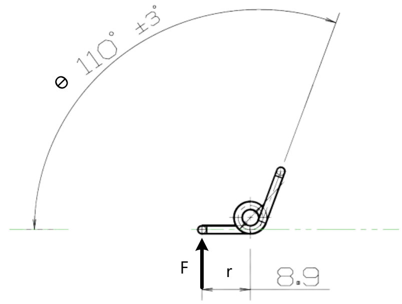


Figure 5. Spring Force Distribution against Locker Table

The results of the finite analysis of simulation elements in locker table products exposed to a working spring force of 181,182 N showed that Von Misses stress had the highest value of 130,6 N/mm2 where the spring was located. The area of maximum stress area on the locker table is shown in Figure 6. The maximum safe stress point has a value of 121,061 N/mm2. The success indicator is indicated by the value of von misses that does not exceed the set yield strength [16]. In this study, the standard yield strength value used is 120 N/mm2. Therefore, the force that works due to the spring against the locker table results in the occurrence of failure criteria in the product. The results of the displacement analysis (Figure 7) or movement that occurs due to the load contained in the locker table show the highest value of 1,7 mm with the lowest value being 1 mm.

(a) (b)

Figure 6. SolidWork Simulation Stress Analysis Result of Locker Table for Stress Analysis (a) Front View, (b) Rear View

(a) (b)

Figure 7. SolidWork Simulation Displacement Analysis Result of Locker for Displacement Analysis (a) Front View, (b) Rear View

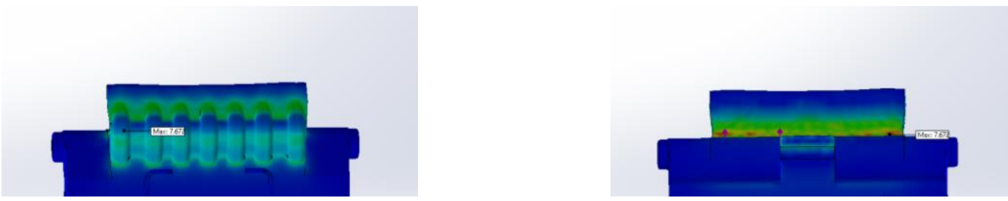
In this simulation, it is important to find out the number of cycles that occur in the locker table with the load given to cause breakage, but this study has obstacles in meeting the POM+25%GF material parameter data that must be included in the simulation. In another study, it is known that cyclic fatigue testing of POM materials, with a high amount of cyclic fatigue will cause an increase in critical stress so that the strength of the material will decrease drastically, besides that the test results show that many cycles will increase the tension by 50% in the notched area and 70% in the blunt area, the thickness of the part also has an important role in this, so that the notched area must be its own concentration when making part design [17].

From the results of the tensile test (Table 4.) where the locker table was given an aging treatment at 50°C and 100°C to determine the influence of environmental temperature on the material. It was found that temperatue had an effect on the tensile strength of POM+25%GF material.

Table 4. Results of Pull Test of Locker Table After Aging Process

69.	**Force (kgf)**	**70.**	**Duration of Aging (jam)**	**71.**	**Temperature (°C)**
72.	79,315	73.	-	74.	Room temperature
75.	68,6	76.	24	77.	50
78.	59,9	79.	24	80.	100

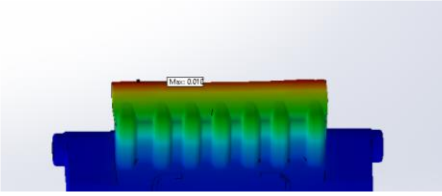
Through a series of experiments and analyses using Solidworks software with finite simulation elements until finally succeeded in developing additional structures on the locker table product in the form of ribs. This rib design is designed to support the load while still paying attention to the material strength limit (material yield value) so that it is not exceeded. The results of this modeling process can be seen in Figure 8 and 9.



(a) (b)

Figure 8. Results of Trial and Error of Rib Structure Development on Locker Table

(a) Front View, (b) Rear View


(a)

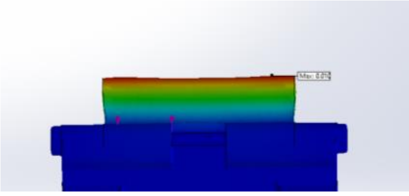

(b)

Figure 9. Results of Trial and Error of Rib Structure Development on Locker Table

(a) Front View, (b) Rear View

Conclusion

From the results of validation and dimensional checks based on design and tolerances, simulations using finite elements to tensile tests, it can be concluded that the force validation of the helical torsion spring on the product shows that the locker table breaks at 121,061 Mpa stress, exceeding the yield strength value that should be broken at a voltage of 150 MPa. Finite analysis of simulation elements on a locker table exposed to spring force shows that the highest Von Misses stress occurs where the spring is located, exceeding the set yield strength value. The tensile test on the locker table with aging treatment at 50°C and 100°C showed the influence of environmental temperature on the tensile strength of POM+25%GF material. The development of an additional structure in the form of ribs was successfully carried out to increase the durability of the locker table against the load.

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