

Design and Construction of a Bending Test Machine Using the VDI 2222 Method and Accuracy Verification Using UTM

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ABSTRAK

Pengujian material plastik merupakan proses pengujian yang dilakukan untuk memastikan sifat kekuatan material plastik dan mendapatkan data sifat mekanik material plastik. Pemilihan jenis material plastik menjadi aspek krusial dalam proses perancangan suatu produk untuk menghasilkan produk dengan kekuatan dan kualitas yang optimal. Pada PT XYZ, ditemukan perbedaan nilai modulus elastisitas antara *data sheet* material dengan kondisi material pada produk aktual. Perbedaan tersebut dapat mempengaruhi batas patah yang tidak sesuai dengan spesifikasi yang ditetapkan. Berdasarkan latar belakang tersebut, diperlukan usulan perancangan mesin uji *bending* produk. Metode VDI 2222 digunakan dalam proses perancangan dan verifikasi pengujian spesimen dengan material PMMA serta standar ASTM D790 menggunakan mesin uji Zwick Roell Z020 yang disertai dengan perhitungan analisis untuk memperoleh tingkat akurasi mesin uji *bending* produk rancangan. Berdasarkan hasil penelitian, diperoleh alternatif desain dari mesin uji *bending* produk yang didasarkan pada daftar persyaratan serta tingkat akurasi dari mesin uji *bending* rancangan. Hasil perhitungan akurasi menunjukkan persentase nilai gaya sebesar 98.63%, persentase nilai *displacement* sebesar 58.67%, dan persentase nilai tegangan sebesar 97.34%. Perbedaan nilai *displacement* yang terjadi diduga disebabkan oleh adanya sistem yang belum sepenuhnya kompatibel serta faktor lain seperti bentuk jig tambahan untuk penekanan yang dinilai kurang tegak lurus dengan bidang penekanan sehingga menjadi faktor yang diasumsikan menyebabkan hasil *displacement* menjadi berbeda. Mesin uji *bending* produk hasil rancangan dinilai belum layak digunakan sebagai alat bantu pengujian kekuatan lentur produk plastik di lingkungan industri. Perlu dilakukan peninjauan kembali terkait kalibrasi *displacement* antara komponen mekanik dengan kontrol elektronik dari mesin uji *bending*.

Kata kunci: Mesin Uji *Bending*; Metode Perancangan VDI 2222; Perpindahan; Uji *Bending* 3 Titik; Verifikasi Pengukuran

ABSTRACT

Plastic material testing is conducted to determine the mechanical properties and strength characteristics of plastic materials. The selection of appropriate plastic material is a critical aspect in product design to ensure optimal strength and quality. At PT XYZ, a discrepancy was identified between the elastic modulus values stated in the material datasheet and those observed in the actual product material. Such differences can affect the fracture limit, resulting in products that do not meet design specifications. In response to this issue, a product bending test machine was proposed and designed. The VDI 2222 methodology was utilized in the design process, and testing was performed using PMMA specimens in accordance with ASTM D790 standards. Verification was conducted using the Zwick Roell Z020 Universal Testing Machine, accompanied by analytical calculations to determine the accuracy of the newly designed machine. The study resulted in alternative design options for the bending test machine based on the requirements list and calculated accuracy levels. The accuracy results showed a force accuracy of 98.63%, displacement accuracy of 58.67%, and stress accuracy of 97.34%. The significant deviation in displacement is suspected to be due to system incompatibility and additional jig components that were not perfectly perpendicular to the pressing plane, leading to measurement errors. The current prototype of the product bending test machine is considered not yet suitable for industrial applications. Further review is required, particularly in calibrating the displacement between the mechanical components and the electronic control system.

Keywords: Bending Testing Machine; Displacement; Measurement Verification; Three Point Bending Test; VDI 2222 Design Method

INTRODUCTION

In the modern industrial era, plastic or polymer materials are frequently used in manufacturing industries. Plastic production output ranks fifth after base metals, motors, chemicals, and food over the past 10 years [1]. The use of plastic materials in the manufacturing industry is supported by advantages that other materials do not possess. Plastic has several advantages, such as being lightweight, flexible, versatile, strong, rust-resistant, colorable, and relatively inexpensive [2]. These factors are what led PT XYZ to use plastic materials in its products.

Material testing needs to be conducted to ensure the material's strength properties and obtain data on the material's mechanical properties. There are several mechanical tests performed to determine these material properties, including tensile tests, compression tests, torsion tests, etc [3]. Among the various tests used to ensure material properties, tensile and compression tests are frequently used types because of their ability to determine material properties more broadly [3]. To ensure the durability of the plastic, testing is conducted before the production process to evaluate the strength of the resulting plastic material properties, one of which is tensile testing [4].

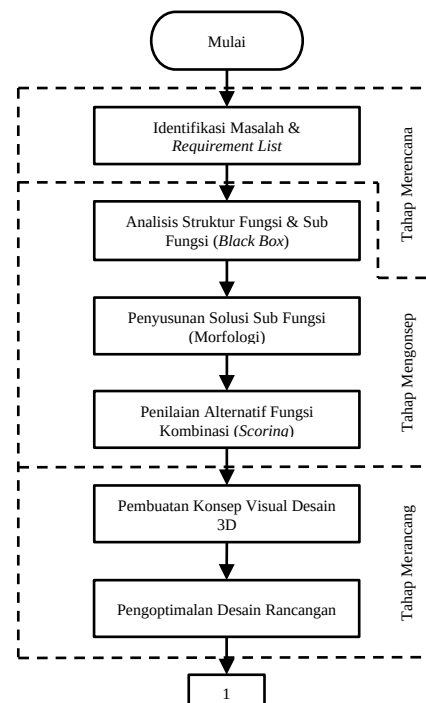
The bending test is one of the testing procedures used to evaluate the strength value of a material thru loading and its elasticity [5]. Testing plastic materials is necessary to obtain the required mechanical properties of a material. One of the mechanical properties of plastic materials obtained thru material testing is the modulus of elasticity. The modulus of elasticity is defined as the mechanical property exhibited by a material to classify and assess its quality [6]. Choosing the right type of plastic material is a crucial aspect in the product design process to produce a product with optimal strength and quality. In the case at PT XYZ, a difference was found in the modulus of elasticity values between the material data sheet and the material condition in the actual product. These differences can affect the mechanical characteristics of the product, such as the breaking limit not meeting the specified requirements. The decrease in the value of the elastic modulus is influenced by the recycled material and injection temperature because increasing the injection temperature of the recycled PP material during the product injection process results in a decrease in the elastic modulus value. Injection temperature is one of the factors that influences the formation of voids in injection-molded product specimens [7]. Increasing the injection temperature and pressure during the production process can affect the

increase in irregularly arranged (amorphous) atoms formed in plastic materials [8]. Based on these findings, the injection process is one of the factors influencing the difference between the modulus of elasticity values on the material data sheet and those observed in the product. Based on the description, research is needed on the design and construction of a bending test machine to test the breaking limit of injection-molded finished products from PT XYZ.

The purpose of this research is to obtain the design results of a bending test machine using the VDI 2222 design method and to compare the accuracy of the machine based on the results of testing the bending test tool with testing using a verified tool using the Zwick Roell Z020 universal testing machine.

RESEARCH METHODS

The research was conducted in two stages, consisting of designing a bending test machine using the VDI 2222 method and performing calculations to analyze the accuracy level of the designed machine. The research object used is the designed bending test machine. The research flowchart is shown in Figure 1.



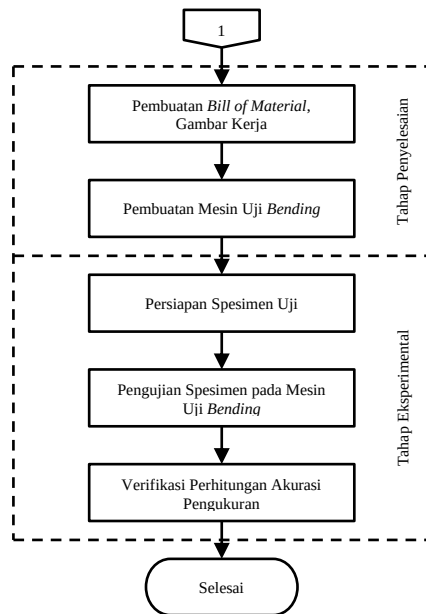


Figure 1 Research Flowchart

The VDI 2222 design method is a systematic approach that defines individual approaches and methods for the conceptual design of technical products suitable for new product development [9]. The use of the VDI 2222 approach method serves to facilitate the product design process, thereby streamlining the learning process and ensuring optimal productivity for designers in problem-solving efforts [10]. There are four stages in the VDI 2222 design method, consisting of the planning stage, the conceptualization stage, the design stage, and the completion stage [11]. The planning stage is carried out to identify the problem and create a list of requirements as the basis for designing [10]. A detailed list of requirements needs to clearly outline the purpose and circumstances under which these demands must be met [9]. The list of requirements obtained should be identified as demands or wishes. A requirement is a condition that must be met under any circumstances; in other words, if one of these requirements is not met, the solution is unacceptable [9]. Desires are requirements that must be considered if possible or provided that they involve limited additional costs [9].

The conceptualization stage is carried out to create a concept based on the list of requirements obtained from the planning stage. There are three stages consisting of creating the function structure, morphology, and scoring. The creation of the function structure is depicted in a black box as the basis for determining the relationship between the input and output signals of the design system. The functional structure can be described as the flow of

energy, materials, and information, represented as functional blocks with inputs and outputs for performing a task [10]. The overall functional structure is used to break down the sub-functions that make up the overall function. To obtain a meaningful and compatible combination of sub-functions into an overall functional structure, it is necessary to create a block diagram where the processes and subsystems within the block (black box) are initially ignored [9]. Subfunctions are used as the basis for creating alternative design concept variations. The morphological approach is used in creating alternative design variations by linking sub-functions and design solutions. The scoring stage is used to determine the best combination function alternative. The scoring stage consists of determining evaluation criteria, creating a weighting preference matrix, the weighting process, and technical and economic evaluation.

During the planning stage, the design for the selected combination of functions is created. The design process was carried out to obtain the visual form of the selected concept in the form of sketch drawings and 3D images. The design results were created to fulfill the conceptual form of the alternative design concepts with more concrete technical details.

The completion stage is carried out for the detailing of the design results that have been created. Detailing is done to meet technical requirements, including detailed technical calculations, the preparation of working drawings, and report documentation for production preparation. Price calculations are necessary as a basis for creating a bill of materials from the design obtained. At the completion stage, the design concept is realized to obtain the physical form of the selected design.

In the experimental stage, testing was conducted on the designed test machine and the Zwick Roell Z20 universal testing machine. The test data collected consisted of quantitative data on force, displacement, and stress values. The test results were used to determine the accuracy comparison between the designed testing machine and a verified testing machine. Testing was conducted according to ASTM D790 standard. PMMA material was used as the specimen with three different thicknesses (1.5mm, 3mm, & 5mm). The testing was performed five times for each thickness. Analytical calculations were performed to determine the voltage value of the designed test machine. The formula is derived from the expansion of the formula obtained from ASTM D790 standard, with the following formula:

$$M_{b \max} = \frac{F \times L}{4} \quad (1)$$

$$c = \frac{d}{2} \quad (2)$$

$$i = \frac{1}{12} \times b \times d^3 \quad (3)$$

$$W_b = \frac{i}{c} \quad (4)$$

$$\sigma_{b \max} = \frac{M_{b \max}}{W_b} \quad (5)$$

as a standard. The accuracy of the machine is determined by analytical calculation using the following formula:

$$\% \text{ Kesalahan} = \frac{\text{Nilai Sebenarnya} - \text{Nilai Eksperimen}}{\text{Nilai Sebenarnya}} \times 100\% \quad (6)$$

$$\text{Akurasi} = 100\% - \% \text{ Kesalahan} \quad (5)$$

Accuracy is an approach used to determine how close the measurement results are to the actual results [12]. Accuracy testing is used to determine the degree of closeness between the measurement results and the actual value or the value accepted

RESULTS AND DISCUSSION

The design process for the bending test machine is based on a request from PT XYZ. The planning stage is carried out to determine the requirement list for the product's bending test machine, obtained thru discussions with PT XYZ, as shown in Table 1.

Tabel 1 Requirement list for product bending testing machine

D / W	Requirements	Technical Evaluation Category	Economic Evaluation Category
Geometri			
W	Clamping the rigid measuring object so that the displacement is read accurately.	Function Cost	Manufacturing Process Cost
W	The measuring instrument clamp can clamp tightly so that it represents a fixed support.	Function Cost	Manufacturing Process Cost
Kinematika			
W	The workpiece clamp has rails so it can be directed.	Function Cost	Manufacturing Process Cost
W	The measuring instrument clamp has rails so it can be directed.	Function Cost	Manufacturing Process Cost
Force			
W	The maximum force that can be applied reaches 450 N.	Function Cost	Material Costs
Energy			
W	Input voltage 220 VAC	Endurance	Operational Costs
Material			
D	The material used is rust-proof.	Endurance	Material Costs
Signal			
D	The tool is capable of applying force to the measured object.	Function Cost	Material Costs
D	The tool is capable of measuring the displacement of the measured object.	Function Cost	Material Costs
D	The measurement results are displayed digitally.	Function Cost	Material Costs
Security			
W	The machine has a cover.	Endurance	Manufacturing Process Cost
Maintenance			
D	The tool can be calibrated.	Ease of Maintenance	Maintenance Costs

The stage continues with the creation of a functional structure using a black box approach. The main and sub-function structures are created to understand the breakdown of the mechanism sequence of the bending test machine. The main function of the designed bending test machine is to

apply a load to the test specimen using linear transmission movement as the driving force for the pressing jig, and to read the values of force and displacement. The structural and functional arrangement is shown in Figure 2.

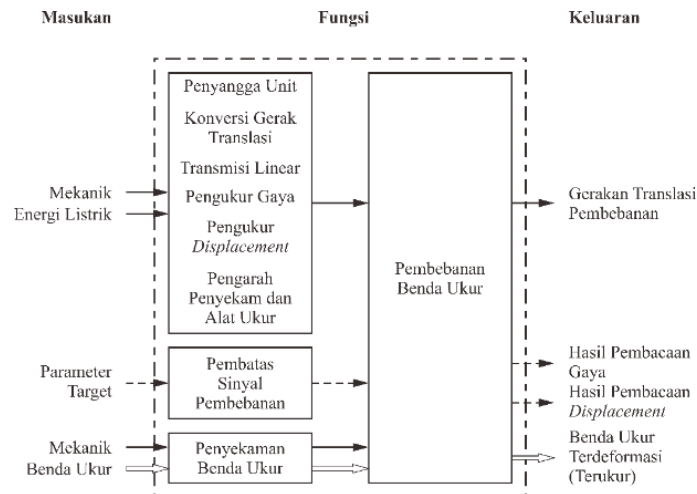


Figure 2 Functional structure of the product bending test machine with a black box approach

The breakdown of sub-functions is used in creating the morphology of the design concept. The morphology is created to obtain several a

combination of mechanisms from a number of sub-functions and solutions. The morphological matrix is shown in Table 2.

Table 2 Morphology Box for Product Bending Test Machine Design

No.	Sub Function	Solution	
		1	2
1	Unit Support	 Aluminium Profile	
2	Translational Motion Conversion	 Single Motor Stepper	 Dual Motor Stepper
3	Linear Transmission	 Ball Screw	 Lead Screw
4	Force Gage	 S Type Load Cell	 In Line Load Cell
5	Displacement Meter	 Magnetic Encoder	
6	Director of Screening and Measuring Instruments	 Lead Screw	
7	Load Signal Limiter	 Arduino MEGA 2560	
8	Measurement Object Recording	 Mekanisme Screw Clamp	
Alternative Function		● AFK 1	● AFK 2

Morphology generation produced 2 alternative function combinations. The process continued with the creation of sketches from the

resulting alternative combinations, serving as an initial visual form of the alternative designs, as shown in Figures 3 and 4.

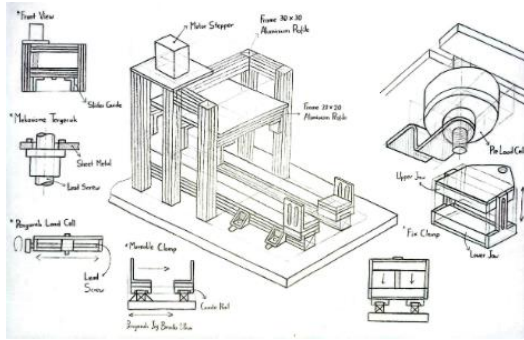


Figure 3 Alternative sketch of combination function 1

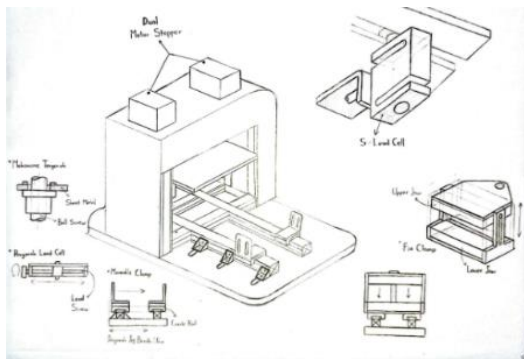


Figure 4 Alternative sketch of the combination function 2

The process continues with the scoring stage, which is used to determine the value of alternative function combinations from both a technical and economic perspective. The process begins with weighting the evaluation criteria, with 3 technical evaluation criteria and 4 economic evaluation criteria. The preference matrix is

created by comparing each technical evaluation criterion, as shown in Figure 5.

A	Fungsi	
B	Daya Tahan	
C	Kemudahan Perawatan	

Figure 5 Preference Matrix for Weighting Technical Evaluation Criteria

The process continues with weighting. The weighting of each criterion is obtained by dividing the number of specific criteria that appear by the total number of criteria that appear. The results of weighting the technical criteria are shown in Table 3.

Table 3 Results of weighting technical criteria

Evaluation Criteria	A	B	C
Number of Each Criterion	2	0	1
Weighted Results	0.67	0	0.33

The process continues with technical evaluation. The technical evaluation phase is conducted by assessing each alternative function combination based on technical evaluation criteria. The obtained value is multiplied by the weight of each evaluation criterion. The technical score is obtained from the accumulation of the product of the score and the weight for each alternative. The technical score is expressed as a percentage, resulting in a higher technical score for AFK 1 compared to AFK 2. The technical assessment results are shown in Table 4.

Table 4 Technical Assessment of the Bending Test Machine

Assessment Aspects	Weight (B)	AFK 1		AFK 2		Ideal Value	
		Value	B × N	Value	B × N	Value	B × N
Function	0.67	3	2.01	4	2.68	5	3.35
Durability	0	3	0	4	0	5	0
Ease of Maintenance	0.33	3	0.99	3	0.99	5	1.65
Technical Value		3		3.67		5	
Percentage (%)		60%		73.4%		100%	
Ranking		2		1			

The stage is followed by economic evaluation. The stage begins with the creation of a preference matrix to compare each economic evaluation criterion. The results of creating the preference matrix for economic evaluation criteria are shown in Figure 6.

A	Biaya Proses Manufaktur			
B	Biaya Material	A		
C	Biaya Operasional	B	A	
D	Biaya Perawatan	D	B	A

Figure 6 Preference Matrix for Weighting Economic Evaluation Criteria

The process continues with weighting. The weighting of each criterion is obtained by dividing the number of specific criteria that appear by the total number of criteria that appear. The results of weighting the economic criteria are shown in Table 5.

Table 5 Results of weighting the economic criteria

Evaluation Criteria	A	B	C	D
Number of Each Criterion	3	2	0	1
Weighted Results	0.50	0.33	0	0.17

The process continues with economic evaluation. The economic evaluation stage is carried out by assessing each alternative function combination based on economic evaluation criteria. The obtained values are multiplied by the weight of each evaluation criterion. The economic value result is obtained from the accumulation of the product of the value and weight for each alternative. The economic value results are presented as percentages, showing that the economic value of AFK 2 is greater than that of AFK 1. The economic evaluation results are shown in Table 6.

Table 6 Economic Evaluation of the Bending Test Machine

Assessment Aspects	Weight (B)	AFK 1		AFK 2		Ideal Value	
		Value	B × N	Value	B × N	Value	B × N
Function	0.50	4	2	4	2	5	2.50
Durability	0.33	4	1.32	4	1.32	5	1.65
Ease of Maintenance	0	5	0	5	0	5	0
Assessment Aspects	0.17	5	0.85	4	0.68	5	0.85
Technical Value		4.17		4		5	
Percentage (%)		83.4%		80%		100%	
Ranking		1		2			

The process continues with the creation of a rating diagram as shown in Figure 7. The diagram rating is used to compare the meeting points between the economic and economic aspects of each alternative function combination. Based on the placement of values on the rating diagram, both concepts are located in quadrant 1. Quadrant 1 position indicates a condition where a concept is in a usable area and is economically sound in terms of solutions.

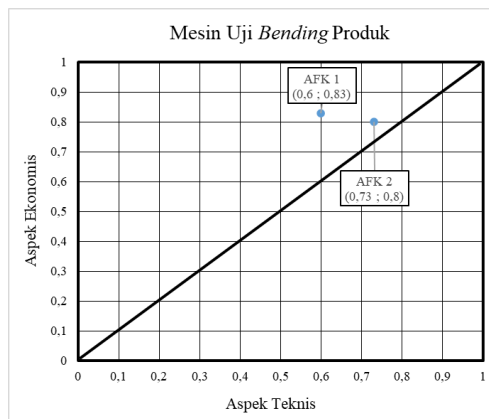


Figure 7 Designed bending test machine rating diagram

Table 7 shows the average technical and economic values of both concepts, where AFK 1 has a value of 0.72 and AFK 2 has a value of 0.77. Based on the technical and economic assessment, alternative combination function 2 (AFK 2) was selected as the final concept because it has a value close to ideal, with a technical value of 0.73 and an economic value of 0.80, and an average value of 0.77.

Table 7 Average Concept Assessment

Evaluation	AFK 1	AFK 2
Technical Value	0,60	0,73
Economic Value	0,83	0,80
Average	0,72	0,77

The process continued with the design phase, which was carried out to obtain a three-dimensional visual form. The Solidworks application was used to create the three-dimensional design, with the results shown in Figure 8.

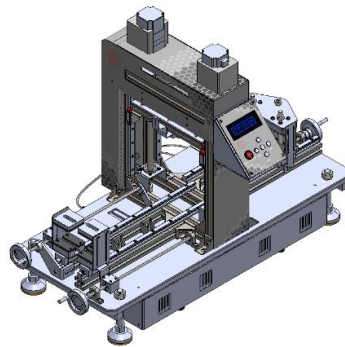


Figure 8 Results of the three-dimensional design of the designed bending test machine

The process continued with the completion stage. The construction of the bending test machine was based on the three-dimensional design and working drawings from the design stage. The results of the bending test machine construction are shown in Figure 9.



Figure 9 Results of the designed bending test machine construction



Figure 10 Zwick Roell Z020 universal testing machine

The process continued with testing the bending test machine. The testing phase was conducted to determine the machine's accuracy in reading force and displacement values. The process begins with the preparation of test specimens using PMMA material. The specimens are made according to ASTM D790 standards with varying thicknesses x , consisting of 1.5 mm, 3 mm, and 5 mm. The dimensions of the specimens are shown in Figure 11.

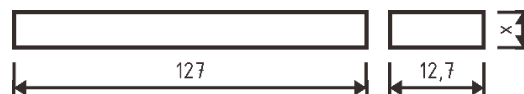


Figure 11 Specimen Testing Dimensions

Testing was conducted using a scheme similar to that shown in Figure 12. The support distance for each thickness used was 24 mm, obtained from 16 times the thickness. The same support distance was used to reduce the repetition of distance adjustments, as each thickness was tested 5 times.

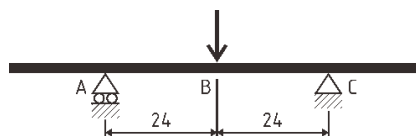


Figure 12 Bending test scheme

The first testing stage was conducted on a Zwick Roell Z020 testing machine as shown in Figure 13, using a photograph of the machine as shown in Figure 10. Testing was conducted by setting the displacement parameter limit to 1.5 mm. The displacement values were obtained thru experimentation, ensuring the testing did not exceed the designed bending test machine's capabilities. Testing was conducted to obtain the average force reading as an input parameter for testing the designed bending test machine. The test results used for accuracy calculation consist of force values, displacement values, and stress values.

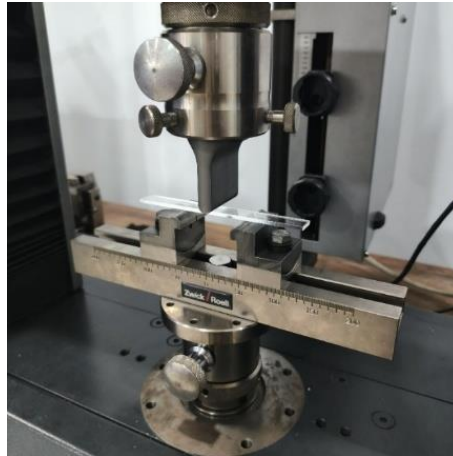


Figure 13 Bending test on Zwick Roell Z020 testing machine

Table 8 Results of specimen testing with the Zwick Roell Z020 testing machine

Specimen	d (mm)	b (mm)	L (mm)	s (mm)	F (N)	σ (MPa)
1	1.5	12.7	48	1.5	7.03	17.71
2	1.5	12.7	48	1.5	7.00	17.64
3	1.5	12.7	48	1.5	6.99	17.62
4	1.5	12.7	48	1.5	7.05	17.75
5	1.5	12.7	48	1.5	7.06	17.79
1	3	12.7	48	1.5	45.60	26.06
2	3	12.7	48	1.5	43.33	27.30
3	3	12.7	48	1.5	42.40	26.71
4	3	12.7	48	1.5	45.12	28.42
5	3	12.7	48	1.5	43.88	27.64
1	5	12.7	48	1.5	226.00	51.25
2	5	12.7	48	1.5	224.35	50.88
3	5	12.7	48	1.5	225.05	51.04
4	5	12.7	48	1.5	226.30	51.32
5	5	12.7	48	1.5	224.49	50.91

Table 8 shows the results of the first test. The process continued with the second test of the designed bending test machine as shown in Figure 13. The test was conducted by inputting the force parameter values obtained from the average of the first test for each thickness. The test results used

for accuracy calculation consisted of force values, displacement values, and stress values. The stress values from the designed bending test machine were obtained thru calculations using equations (1) to (5).



Figure 14 Bending test on the designed testing machine

Table 9 Results of the designed bending test machine testing

Specimen	d (mm)	b (mm)	L (mm)	F (N)	s (mm)	σ (MPa)
1	1.5	12.7	48	7.19	1.39	18.13
2	1.5	12.7	48	7.19	1.42	18.13
3	1.5	12.7	48	7.67	1.22	19.34
4	1.5	12.7	48	7.67	1.37	19.34
5	1.5	12.7	48	7.67	1.52	19.34
1	3	12.7	48	44.59	2.27	28.09
2	3	12.7	48	44.59	2.14	28.09
3	3	12.7	48	44.59	2.32	28.09
4	3	12.7	48	44.11	2.37	27.79
5	3	12.7	48	44.11	2.30	27.79
1	5	12.7	48	228.23	2.63	51.75
2	5	12.7	48	228.23	2.81	51.75
3	5	12.7	48	228.23	2.74	51.75
4	5	12.7	48	227.27	2.75	51.54
5	5	12.7	48	228.71	2.56	51.86

The process continues with the calculation of the testing machine's accuracy. This stage begins with calculating the average for each force value, displacement value, and stress value, as shown in Tables 10, 11, and 12.

Table 10 Results of average force value calculation

Thickness of Measured Object (mm)	Zwick Roell Z020 Testing Machine (N)	Designed Testing Machine (N)
1.5	7.03	7.48
3	44.06	44.40
5	225.24	228.13
Average	92.11	93.37

Table 11 Results of average displacement value calculation

Thickness of Measured Object (mm)	Zwick Roell Z020 Testing Machine (N)	Designed Testing Machine (N)
1.5	1.5	1.38
3	1.5	2.28
5	1.5	2.70
Average	1.5	2.12

Table 12 Results of average voltage calculation

Thickness of Measured Object (mm)	Zwick Roell Z020 Testing Machine (N)	Designed Testing Machine (N)
1.5	17.70	18.85
3	27.23	27.97
5	51.08	51.73
Average	32.00	32.85

The process continues with accuracy calculations. This stage begins with calculating the percentage error for each average value of force, displacement, and stress. Based on equations (5)

and (6), the calculation results are shown in Table 13.

Table 13 Results of error calculation and accuracy of test results

Calculation Results	Percentage of Force	Percentage of Displacement	Percentage of Stress
Error	1,37%	41,33%	2,66%
Accuracy	98,63%	58,67%	97,34%

The calculation results for accuracy show two values that are close to the actual values: the force value is 98.63% and the voltage value is 97.34%. The error values for the force value are 1.37% and for the voltage value are 2.66%, which is the difference between the test results, where the experimental values for these parameters are higher than the actual values. The calculation results for the displacement parameter show an error value of 41.33%, causing the accuracy level to reach only 58.67%. This is due to a difference with varying ranges in the displacement test results.

The difference in displacement values observed is believed to be caused by a system that is not fully compatible. Another cause, looking at the mechanical components, is that measurement errors can be caused by the shape of the additional pressing jig, which is considered less perpendicular to the pressing surface, thus being a factor assumed to cause different displacement results.

CONCLUSION

Based on the results of the Design and Construction of a Bending Testing Machine Using the VDI 2222 Method and Accuracy Verification Using UTM, it can be concluded that this research resulted in the design of a product bending testing machine using the VDI 2222 design method, which

is based on the requirements list from PT XYZ. The results of the analysis of the machine's accuracy showed that the displacement accuracy value was considered to have a low level of accuracy, so the designed bending testing machine was deemed not yet suitable for use as an aid for testing the flexural strength of plastic products. A review is needed regarding the displacement calibration between mechanical components and electronic controls.

REFERENCES

- [1] Artha R P, Anindita S F, Iskandar M I. Tren Produksi dan Konsumsi Plastik di Indonesia. *Danareksa Research Institute* (17 Maret 2023); diakses pada 3 Maret 2025, dari <https://danareksa.co.id>.
- [2] Yuliyawati Y, Kamaluddin M. Persepsi Konsumen Terhadap Kebijakan Kantong Plastik Berbayar. *Jurnal Sosial, Filsafat, dan Komunikasi* 2021; 15(1): 48-54.
- [3] Ramagisandy H, Siswanto R. Analisa Hasil Uji Kekuatan Tarik, Tekan & Struktur Makro Sampah Plastik Jenis PET, HDPE, dan Campuran (PET+HDPE). *Jurnal Tugas Akhir Mahasiswa Rotary* 2021; 3(2): 245-258.
- [4] Fitriyanti, Ikhsan K. Studi Kuat Tarik Bioplastik dan *Edible Film* dengan Metode *Bending* ASTM D638-02A. *Jurnal Sains Fisika* 2023; 3(1): 1-8.
- [5] Gautama C, Alfatih M F, Alimi S. Eksperimen Uji Bending Pada Komposit Resin Polyester dan Epoxy Serat Jerami Padi dengan Proses Hand Lay Up. *Jurnal Teknik, Elektronik, Engine* 2022; 8(2): 237-242.
- [6] Wirman R P, Isnaini V A, Kartika R, Wirman S P. Rancang Bangun Alat Ukur Modulus Elastisitas Material dengan Menggunakan Sensor *Force Gauge* dan *Video Tracker*. *Journal Online of Physics* 2023; 8(2): 61-65.
- [7] Hakim J, Joharwan J W, Palmiyanto M H. Pengaruh Beda Temperatur Proses Injeksi Terhadap Sifat Mekanis Bahan *Polypropylene* (PP) Daur Ulang. *Jurnal Material dan Proses Manufaktur* 2020; 4(2): 124-135.
- [8] Grigore M E. *Methods of Recycling, Properties and Applications of Recycled Thermoplastic Polymers*. *Recycling Journal* 2017; 2(4): 1-11.
- [9] *Engineering Design: A Systematic Approach (Third Edition)*. London, United Kingdom: Springer-Verlag London Limited; 2007.
- [10] Adi N M P, Winata P, Nugraha A, Hutama A S. Perancangan Mesin *Conveyor* untuk Peningkatan Efisiensi Produksi di PT XYZ. *Jurnal Kajian Teknik Mesin* 2023; 8(2): 58-69.
- [11] Adhiharto R, Nusantara A B, Komara A I, Wigenaputra D H. Perancangan Ulang dan Analisa Mesin *Benchtop Injection Molding* dengan Metode VDI 2222. *Jurnal Teknologi dan Rekayasa Manufaktur* 2023; 5(2): 153-168.
- [12] Resmiati, Putra M E. Akurasi dan Presisi Alat Ukur Tinggi Badan Digital untuk Penilaian Status Gizi. *Jurnal Endurance : Kajian Ilmiah Problema Kesehatan* 2021; 6(3): 616-621.