MARMARA UNIVERSITY
FACULTY OF ENGINEERING

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DESIGNING, ANALYZING, MANUFACTURING, AND TESTING OF SCREW SIDE ACTION TENSILE GRIP

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by

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ÖZET

Bu çalışma, Shimadzu AGS-X evrensel test cihazı ile uyumlu olarak kullanılmak üzere tasarlanan, analiz edilen, imal edilen ve test edilen bir vidalı yan sıkmalı (screw side action) tutucu sistemine odaklanmaktadır. Vidalı yan sıkmalı mekanik tutucular, özellikle metal, plastik ve kompozit gibi rijit malzemelere ait düzlemsel test numunelerinin çekme testlerinde, güvenli, ekonomik ve etkili bir tutma yöntemi sunmaktadır. Harici bir güç kaynağına ihtiyaç duymadan manuel olarak çalışan bu tutucular; basit yapıları, ayarlanabilir çene açıklıkları ve eksenel hizalama kabiliyetleri sayesinde laboratuvar uygulamalarında önemli avantajlar sağlamaktadır.

Projenin temel amacı, farklı boyutlardaki düzlemsel numunelere uyum sağlayabilen, eksenel yükleme altında kaymayı önleyebilen ve yapısal olarak güvenilir bir tutucu mekanizması geliştirmektir. SolidWorks yazılımı kullanılarak özel bir tutucu tasarımı oluşturulmuş; korozyon direnci ve mekanik dayanımı yüksek olan AISI 304 paslanmaz çelik, malzeme olarak tercih edilmiştir. Tutucunun yapısal güvenliği, kesme ve eğilme etkileri altında oluşan gerilmeler analitik yöntemlerle değerlendirilmiştir.

Sayısal analiz sonuçlarının doğrulanması amacıyla ANSYS Workbench kullanılarak Sonlu Elemanlar Analizi (FEA) gerçekleştirilmiştir. Üretim sürecinde CNC işleme yöntemleri kullanılmış ve ISO 286 standardına uygun tolerans-geçme ilişkileri belirlenmiştir. Prototip üretimin ardından çeşitli test numuneleri üzerinde deneysel çalışmalar gerçekleştirilmiş ve geliştirilen tutucunun yük aktarımı, hizalama ve kayma direnci açısından performansı değerlendirilmiştir.

Elde edilen sonuçlar, sayısal ve deneysel veriler arasında uyum olduğunu göstermiş; geliştirilen tutucunun, standart testlerde numune bütünlüğünü koruyarak güvenli ve tekrarlanabilir ölçümler sağladığı doğrulanmıştır. Bu çalışma, mekanik testlerde kullanılan tutucu sistemlerin geliştirilmesine katkı sunmakta ve ileriye dönük çalışmalara katkı sunmaktadır.

ABSTRACT

This study focuses on the design, analysis, manufacturing, and testing of a screw side action grip developed for compatibility with the Shimadzu AGS-X universal testing machine. Screw side action mechanical grips provide a safe, economical, and effective method for holding flat test specimens made of rigid materials such as metals, plastics, and composites during tensile tests. Operating manually without the need for an external power source, these grips offer significant advantages in laboratory applications due to their simple structure, adjustable jaw openings, and precise axial alignment capabilities.

The primary objective of the project is to develop a structurally reliable gripping mechanism capable of accommodating flat specimens of various sizes while preventing slippage under axial loading. A custom grip design was created using SolidWorks software, and AISI 304 stainless steel was selected as the material due to its high corrosion resistance and mechanical strength. The structural integrity of the grip was evaluated through analytical methods considering shear and bending stresses.

To verify the analytical results, Finite Element Analysis (FEA) was performed using ANSYS Workbench. During the production phase, CNC machining techniques were utilized, and fit and tolerance relations were defined in accordance with ISO 286 standards. After prototype fabrication, experimental tests were conducted using various test specimens, and the performance of the developed grip was evaluated in terms of load transmission, alignment, and slip resistance.

The results demonstrated consistency between numerical and experimental data, confirming that the developed grip maintains specimen integrity and enables safe and repeatable measurements in standard tensile tests. This study contributes to the advancement of gripping systems used in mechanical testing and provides a solid foundation for future research and development.

SYMBOLS

σ_y	Yield strength (MPa)
τ_{shear}	Shear stress (MPa)
F	Applied tensile force (N)
A_s	Tensile stress area of guide pin (mm^2)
M	Applied moment (N·m)
mm	millimeters
cm	centimeter
m	meter
e	distance (mm)
Pa	Pascal
N	Newton
MPa	Mega Pascal
σ_{vm}	von Mises equivalent stress (MPa)
τ_{allow}	Allowable shear stress (MPa)

ABBREVIATIONS

3D – Three-Dimensional

AGS-X – Autograph Graphical Series X

ANSYS – Analysis System Software (by ANSYS Inc.)

ASTM – American Society for Testing and Materials

CAD – Computer-Aided Design

CNC – Computer Numerical Control

FDM- Fused Deposition Modeling

FEA – Finite Element Analysis

FEM – Finite Element Method

FoS – Factor of Safety

ISO – International Organization for Standardization

N – Newton

PLA- Polylactic Acid

SS – Stainless Steel

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1. INTRODUCTION

Tensile testing devices, commonly referred to as universal testing machines (UTMs), play a critical role in evaluating the mechanical behavior of materials under uniaxial load conditions. These machines enable the determination of fundamental properties such as ultimate tensile strength, yield strength, elongation at break, and elastic modulus, which are essential for material

-X series represents a modern generation of universal testing machines designed to deliver selection, structural design, and quality assurance across a wide range of engineering applications.

The development of such device's dates back to the industrial revolution, when the need for standardized and reproducible material testing became apparent in the context of mass production and infrastructure development. Early testing machines operated mechanically and provided limited data, but they laid the foundation for modern systems. Over time, advancements in electromechanical components, data acquisition technologies, and automation have transformed tensile testing into a highly precise and reliable process. Contemporary testing machines are equipped with digital controls, high-resolution sensors, and flexible software platforms, allowing for complex test protocols and detailed analysis. Today, these devices are indispensable in industries such as aerospace, automotive, biomedical engineering, and construction, as well as in academic research and education.

1.1. Overview of the Shimadzu AGS-X Series

The Shimadzu AGShigh-precision mechanical testing with ease of use and adaptability. Engineered for a wide range of applications, the AGS-X series supports tensile, compression, bending, and shear testing across various materials, including metals, polymers, composites, and textiles (figure-1).

The system features a robust, high-rigidity frame and an electromechanical drive that ensures accurate load application and crosshead displacement, even under dynamic test conditions.

One of the key advantages of the AGS-X series is its modular structure, which allows users to integrate a variety of grips, fixtures, extensometers, and load cells depending on the specific test requirements. Coupled with Shimadzu's TRAPEZIUM X software, the system offers real-time data acquisition, customizable test methods, and compliance with international testing standards such as ASTM and ISO. These features make it particularly suitable for both routine quality control operations and advanced research experiments.

Figure 1.1 Shimadzu AGS-X 50 kN

The AGS-X series is also known for its compatibility with custom-designed fixtures, offering researchers and engineers the flexibility to develop specialized test setups. This adaptability makes the AGS-X not only a commercial testing solution but also a powerful platform for prototyping and evaluating novel mechanical testing tools, such as the custom-designed screw action grip presented in this thesis.

1.2. Accessories in Tensile Testing Machines

In tensile testing, the reliability of experimental data depends not only on the mechanical integrity of the testing frame but also more critically on the accessories that facilitate precise load application and deformation measurement. Accessories such as grips, extensometers, load cells, and test fixtures are integral to the system's functionality, as they enable the machine to interact meaningfully with different specimen types under standardized test conditions. Each of these components serves a specific purpose, whether it be transmitting force, measuring strain, or supporting non-standard test setups. Particularly in advanced systems like the Shimadzu AGS-X, the modularity and compatibility of these instruments allow for testing across a wide range of materials and geometries. Sections 1.3 and 1.4 provide a concise overview of the principal accessories used with the AGS-X system, highlighting their function, design features, and relevance to this study.

1.2.1. Grips

Grips are one of the most critical components in tensile testing, as they directly influence the reliability, repeatability, and accuracy of the results. Their primary function is to hold the specimen firmly in place throughout the test, ensuring that the applied tensile force is transmitted uniformly along the test axis without slippage, misalignment, or stress concentration. Improper gripping can lead to premature specimen failure, erroneous data, or even damage to the testing machine itself. Therefore, the selection of appropriate grip type is essential and must consider the material properties, specimen geometry, and testing standards.

1.2.2. Wedge Grips

Wedge grips operate on a self-tightening principle, where the jaws grip more tightly as tensile force increases. This makes them ideal for high-strength materials or tests involving significant axial loads. Their mechanical design allows for automatic load alignment, reducing the risk of eccentric loading.

Figure 1.2 Mechanical wedge grip

1.2.3. Pneumatic and hydraulic grips

They utilize pressurized air or fluid to achieve rapid, uniform clamping. These grips are advantageous for repetitive testing and materials that are sensitive to stress concentrations, such as elastomers or films. They also reduce operator variability by providing consistent clamping force across multiple tests.

Figure 1.3 Pneumatic and hydraulic grips

1.2.4. Screw action grips

They are the subject of this thesis, offer manually controlled clamping through a threaded mechanism. While they require more time to operate compared to automated systems, their simplicity, low cost, and fine adjustment capabilities make them especially valuable in academic laboratories, research settings, and prototype testing. These grips are particularly useful when frequent changes in specimen size or material type are involved, as they can be easily adjusted without the need for special tools or equipment. Furthermore, the mechanical feedback provided by the tightening process allows the user to feel and control the clamping force with high sensitivity, which can be advantageous when dealing with fragile specimens.

Figure 1.4 Screw action grip

In this thesis, a custom-designed screw action grip was developed specifically for the AGS-X system, aiming to provide a reliable, adaptable, and cost-efficient alternative to commercial solutions.

1.2.5. Extensometers

Extensometers are critical for measuring the elongation of a specimen during tensile testing, allowing for the accurate calculation of strain-related properties such as Young's modulus and yield strain. Without precise strain data, mechanical characterization remains incomplete, especially for materials where elastic behavior is prominent.

The Shimadzu AGS-X series supports both **contact** and **non-contact** extensometers.

Contact extensometers physically attach to the specimen and are widely used due to their affordability and straightforward setup. However, they may not be suitable for very soft or fragile materials, as contact can influence test behavior.

Figure 1.5 Contact extensometer

Non-contact extensometers, such as video or laser systems, offer high-precision measurement without physically touching the specimen. These are ideal for delicate materials or dynamic tests.

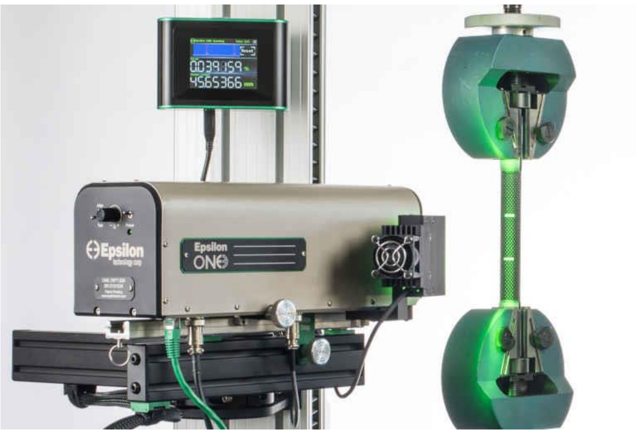

Figure 1.6 non-contact extensometer

1.3. Literature Review

This section reviews the existing literature on tensile testing grips, with a focus on screw action grip systems. It also highlights relevant international standards and identifies gaps in the current research, particularly concerning the compatibility of custom grips with the Shimadzu AGS-X universal testing machine.

Grip design plays a critical role in the reliability of tensile testing. According to ASTM E8 and ISO 6892 standards, improperly designed or misaligned grips can cause slippage, uneven stress distribution, or premature specimen failure—ultimately compromising the validity of test results. The selected gripping method must ensure axial alignment, consistent clamping force, and minimal stress concentration at the contact surface.

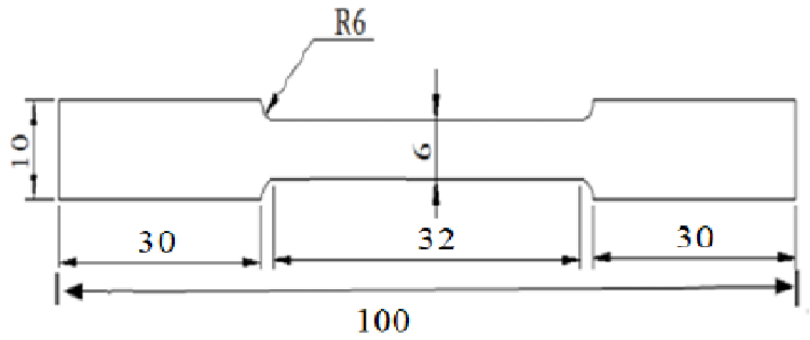

Figure 1.7 Geometry of a Tensile Sample (ASTM-E8)

Numerous studies (e.g., Zhang et al., 2018; Kumar & Patel, 2020) have examined how grip geometry, jaw surface texture, and clamping mechanisms influence test outcomes. These studies consistently point to the importance of selecting grip systems appropriate to specimen material, shape, and expected load conditions.

1.4. Screw Action Grips

Screw action grips are among the simplest and most versatile types used in tensile testing. They offer manual control over the clamping force and jaw pressure, making them suitable for laboratories that require frequent adjustments or work with a variety of sample sizes and materials. Unlike pneumatic or hydraulic systems, they do not require external power sources or control equipment, which makes them a cost-effective alternative for educational and research environments.

Commercially available screw grips—such as those offered by Instron, Shimadzu, and AHP—typically feature hardened steel jaws, self-centering mechanisms, and knurled contact surfaces.

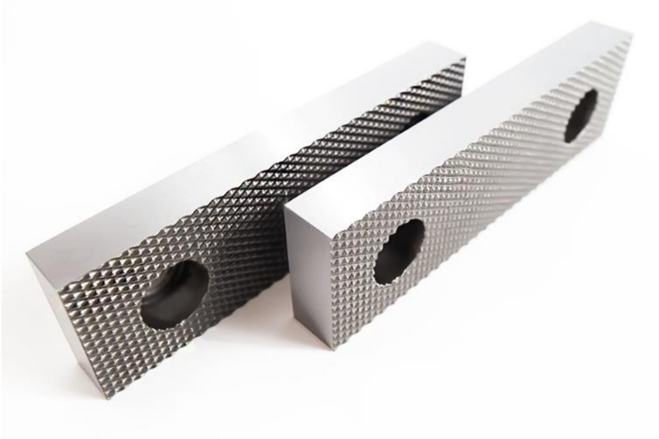

Figure 1.8 Knurled contact surface

1.4.1. Standardization and Testing Protocols

The use and performance requirements of grip systems are governed by several international standards. Some of the most relevant include:

ASTM E8/E8M: Standard Test Methods for Tension Testing of Metallic Materials

ASTM D638: Tensile Properties of Plastics

ASTM D412: Tensile Testing of Rubber and Elastomers

ISO 6892: Metallic Materials – Tensile Testing

These standards emphasize the need for uniform stress distribution, axial force application, and minimal slippage at the grip–specimen interface. They also outline requirements for extensometer use, gauge length, and strain rate control—all of which relate to the grip design.

2. DESIGN AND MANUFACTURING

This section covers the complete design and manufacturing process of the screw action grip developed for the Shimadzu AGS-X universal testing machine. The design was conducted in line with ASTM and ISO standards, considering the physical constraints of the AGS-X platform. Critical factors such as force distribution, stress concentration, alignment, and ease of manufacturing were considered throughout the development process. A CAD model was created. After the cad model, the first prototype is produced by pla material. Then, manufacturing process conducted.

2.1. Design Criteria and Functional Requirements

The design aimed to provide secure and repeatable specimen clamping while ensuring full compatibility with the AGS-X system. Functional requirements included:

- **Compatibility**: Direct mounting interface with Shimadzu AGS-X crosshead and base
- **Clamping Force**: Minimum 2 kN capacity without slippage
- **Specimen Range**: Accommodates flat and round specimens (2-10 mm thickness)
- **Operational**: Manual screw-action mechanism for precise force adjustment
- **Standards Compliance**: ASTM E8 and ISO 6892 requirements for tensile testing
-

2.2. CAD Modeling

The selected design was modeled in 3D using SolidWorks and shown in figure 2.1

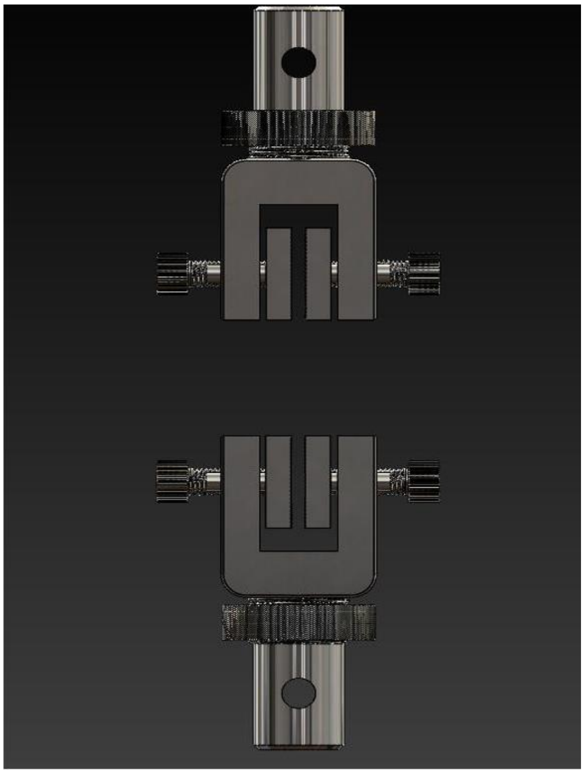

Figure 2.1 CAD Model of Screw Action Grip

According to the test specimen standards the gap between jaws have been selected as 10 mm and dimensions of the grip parts are shown in figure 2.2 below.

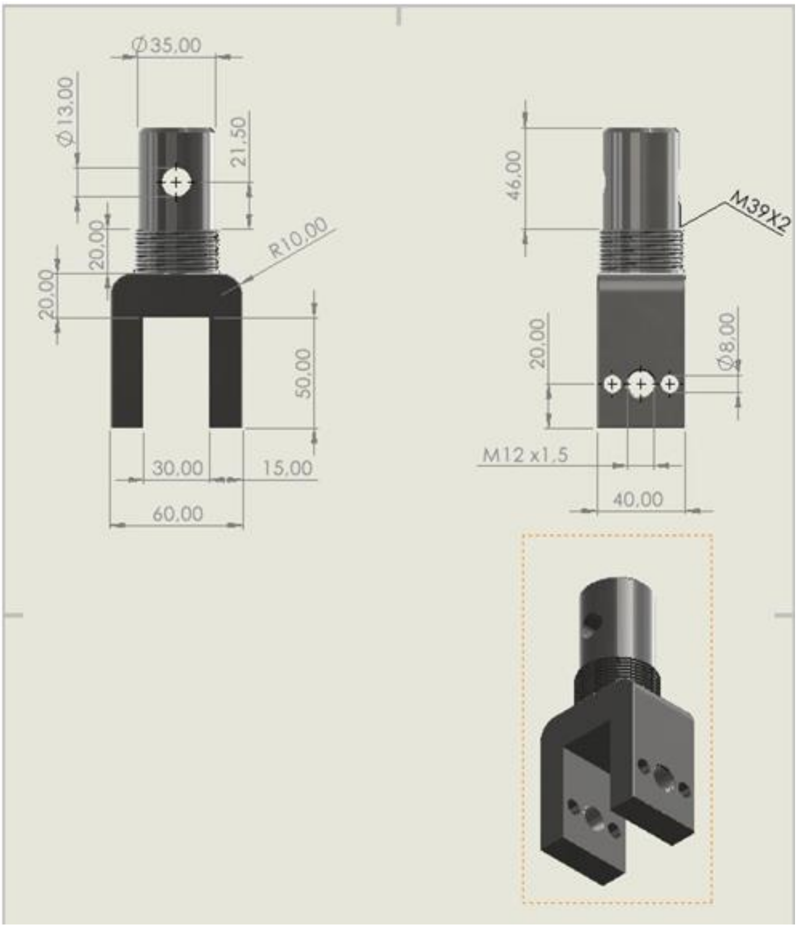

Figure 2.2 Dimension of the Grip

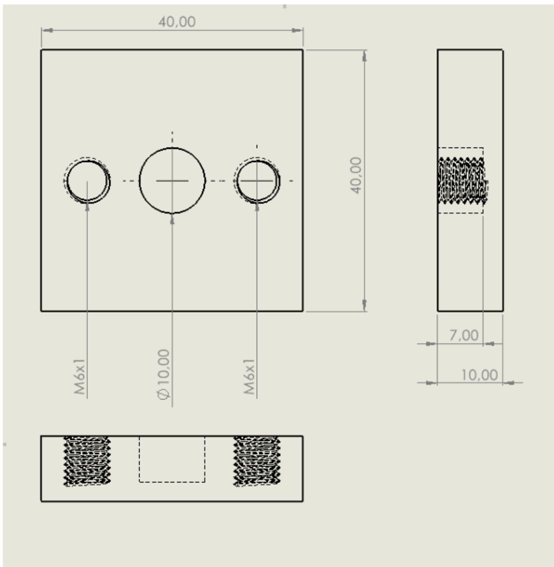

Figure 2.3 Dimension of the Knurled Grip

The main part which carries the load in the grip is guide pins. The maximum shear stress occurs in these parts. So, according to the design requirements and raw material standards pin dimensions are selected as in the figure 2.4.

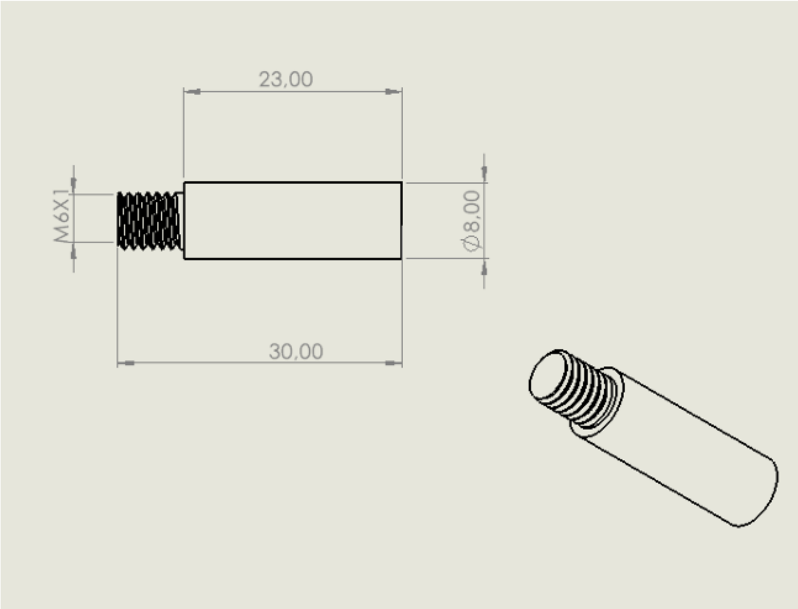

Figure 2.4 Dimensions of Guide Pin

Lastly the connector ring which fixes the grip to the testing machine is designed as in figure 2.5.

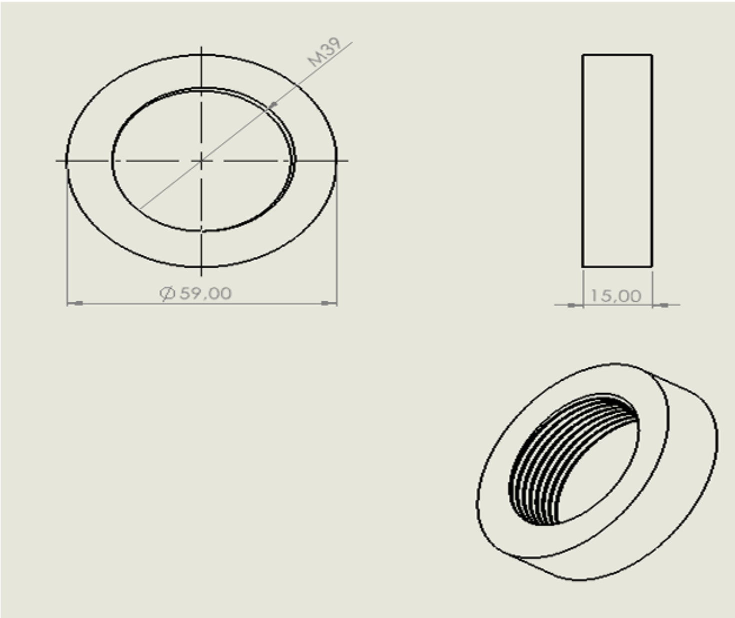

Figure 2.5 Dimensions of Connector Ring

2.3. Material Selection

Several alternative materials were considered during the selection process:

- **AISI 316 Stainless Steel**: Offers superior corrosion resistance due to the presence of molybdenum. However, it is more expensive and not strictly necessary for dry lab environments where chloride exposure is minimal.

- **AISI 1020 Carbon Steel**: While more economical and easier to machine, it lacks corrosion resistance and aesthetic durability of stainless steels. It also requires protective coatings, which can complicate maintenance.

- **7075-T6 Aluminum Alloy**: Known for its high strength-to-weight ratio, but not ideal for clamping elements due to its relatively low hardness and wear resistance. Also susceptible to galling and surface damage over time.

In tensile testing applications, material selection is vital to ensure structural integrity, durability, and reliable performance under load. For this project, AISI 304 stainless steel was chosen as the main material for the screw side action grip due to its mechanical strength and corrosion resistance.

AISI 304 is an austenitic stainless steel containing approximately 18% chromium and 8% nickel, which provides a balance of ductility, strength, and corrosion resistance. Its yield strength (~215 MPa) and ultimate tensile strength (~505 MPa) are sufficient for the loading conditions expected during the operation of the grip, particularly under axial tensile forces up to 5 kN. The material's toughness and fatigue resistance also make it suitable for repeated loading-unloading cycles typical in laboratory testing scenarios.

2.4. Manufacturing Process

The manufacturing of the grip components was carried out in collaboration with **ERSİN MAKİNE**, a precision machining company that supported the project by providing access to industrial-grade CNC equipment and technical expertise. All fabrication processes were performed in a professional workshop setting, ensuring dimensional accuracy and production quality in line with engineering standards.

2.4.1. Raw Material Preparation

The raw material used in this project consisted of 60×60 mm AISI 304 stainless steel bars. These bars were sectioned into blocks using an industrial band saw, allowing for the fabrication of both the main body. Cutting dimensions were optimized to reduce material waste and shorten machining time in the subsequent manufacturing stages.

Additionally, 20×60 mm AISI 304 flat bars were cut to size to be used specifically for the gripping parts.

As illustrated in **Figure 2.6**, the machining stages of the raw material are presented. In the first operation, the workpiece was mounted on a CNC lathe, where it was turned into a cylindrical shape and threaded features were machined.

Figure 2.6 First Operation of Raw Material

As shown in **Figure 2.7**, the inner regions of the jaw were machined using a CNC milling machine to create cavities and prepare the part for subsequent drilling operations. Due to the machining difficulty of AISI 304 stainless steel, particular attention was given to cutting parameters. Using CAM software, the depth of cut per pass was limited to **0.2 mm** to match the material's characteristics. This approach resulted in a time-intensive but precise machining process that ensured dimensional accuracy and tool safety.

Figure 2.7 CNC Milling Operation of the Jaw

2.5. Assembly and Machine Fitment

The grip components were assembled manually using M8 socket head cap screws, ensuring rigid and secure connections between the parts. Assembly was followed by a test fit on the Shimadzu AGS-X Universal Testing Machine, where the compatibility and alignment of the grip with the machine's load axis were verified.

Manual tightening was performed using a torque wrench to apply a consistent preload and avoid bolt loosening during testing.

Thread lubrication was applied to achieve uniform torque and reduce galling in stainless steel threads.

During fitment, adjustments were made to align the jaws precisely along the vertical loading axis, ensuring uniform load distribution and avoiding off-axis stress concentrations.

Figure 2.8 shows the fully assembled screw side action grip mounted on the Shimadzu AGS-X machine.

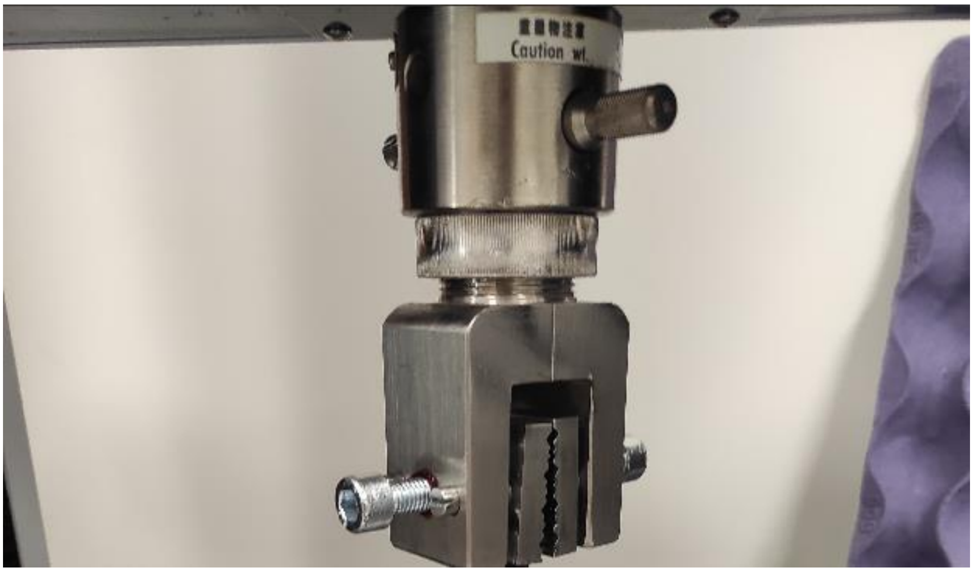

Figure 2.8 Screw Side Action Tensile Grip Mounted on Shimadzu AGS-X

3. STRUCTURAL SAFETY ANALYSIS AND VALIDATION

To ensure the mechanical integrity and operational reliability of the screw side action grip under tensile loading, a comprehensive structural safety assessment was conducted. This evaluation involved both analytical stress calculations and numerical simulations using Finite Element Analysis (FEA).

The analysis focused on critical regions of the grip where mechanical failure is most likely to initiate, such as the guide pins, threaded connections, and clamping jaws. Particular attention was paid to combined loading scenarios, including shear, bending, and contact stress, to assess whether the design meets acceptable safety margins.

3.1. Governing equations and Theoretical Background

The structural integrity of the screw side action grip critically depends on the ability of its components to withstand combined loading conditions without failure. Among the components, the **guide pin** is the most critical element, as it directly transfers the clamping load and experiences the highest stress concentrations due to combined **bending** and **shear** effects.

The load applied on the guide pin generates a **shear force** as well as a **bending moment** because of the eccentric positioning of the applied load relative to the pin axis.

3.1.1. Shear Stress on Guide Pin

The shear stress τ on the pin cross-section is calculated by:

$$F_{shear} = \tau \cdot A_s \tag{3.1}$$

$$A_s = \frac{\pi d^2}{4} \tag{3.2}$$

3.1.2. Bending Stress on Guide Pin

Due to the eccentric loading, the guide pin experiences bending moment M defined by:

$$M = F.e \tag{3.3}$$

where e the moment arm (eccentricity), the perpendicular distance from the line of action of the force to the neutral axis of the pin.

The maximum bending stress σ in the pin is calculated as:

$$\sigma = \frac{Mc}{I} = \frac{32M}{\pi d^3} \tag{3.4}$$

3.1.3. Von Mises Equivalent Stress

The combined effect of bending and shear stresses is assessed using the Von Mises equivalent stress σ_{vm}:

$$\sigma_{vm} = \sqrt{\sigma^2 + 3\tau^2} \tag{3.5}$$

3.1.4. Safety Considerations:

The calculated Von Mises stress must be compared with the allowable stress, determined by the material's yield strength σ_{vm} divided by a chosen factor of safety (FoS):

$$\sigma_{vm} \leq 0.577 \frac{\sigma_y}{FoS} \tag{3.6}$$

3.2. Calculation

To evaluate the structural safety of the guide pin used in the screw side action grip, analytical stress calculations were performed using combined bending and shear loads. The goal of this analysis is to determine the **maximum allowable axial force (F_{max})** that can be safely applied to a single pin, based on the Von Mises stress criterion and a factor of safety (FoS) of **2.5**.

According to the equation-6 σ_{vm} can be calculated as:

$$\sigma_{vm} \leq \frac{215}{2.5} \tag{3.7}$$

$$\sigma_{vm} = 86\ MPa \tag{3.8}$$

Shear stress on the pin according to the **equation 1:**

$$\tau = \frac{4F}{\pi d^2} \tag{3.9}$$

So:

$$\tau = \frac{4F}{\pi 0.008^2} = 19894.36F \tag{3.10}$$

Bending stress on the pin according to the **equation 3 and 4:**

$$M = 0.005F \tag{3.11}$$

$$\sigma = \frac{32(0.005F)}{\pi 0.008^3} = 99471.8F \tag{3.12}$$

Substituting into **equation 5**:

$$86 = \sqrt{(99471.8F)^2 + 3(19894.36F)^2} \tag{3.13}$$

$$86000000 = \sqrt{(99471.8F)^2 + 3(19894.36F)^2} \tag{3.14}$$

$$F_{max} \approx 816\ N \tag{3.15}$$

So, one grip has only 4 guide pins. Total maximum tensile force must be **3267 N**.

3.3. Finite Element Analysis (FEA)

In order to evaluate the mechanical performance and structural safety of the screw side action grip beyond analytical estimations, a finite element analysis (FEA) was conducted using **ANSYS Workbench 2022 R1**. This analysis aimed to assess stress distributions, identify critical stress regions, and verify that the design remains within safe operational limits under the expected service load as **3267 N**.

3.3.1. Mesh Generation and Model Setup

The solid model created in **SolidWorks** was imported into ANSYS for simulation. A tetrahedral element type was used, with refined meshing applied to geometrically sensitive areas, particularly around the **guide pin holes**, threads, and clamping surfaces where high stress concentrations were anticipated. Mesh independence was ensured by performing a mesh convergence study. The final model contained approximately **394802 nodes** and **273737 elements**, with a minimum element size of **0.8 mm** at the contact interfaces.

Figure 3.1 shows the simulation setup for the 3267 N force with the fixed surface.

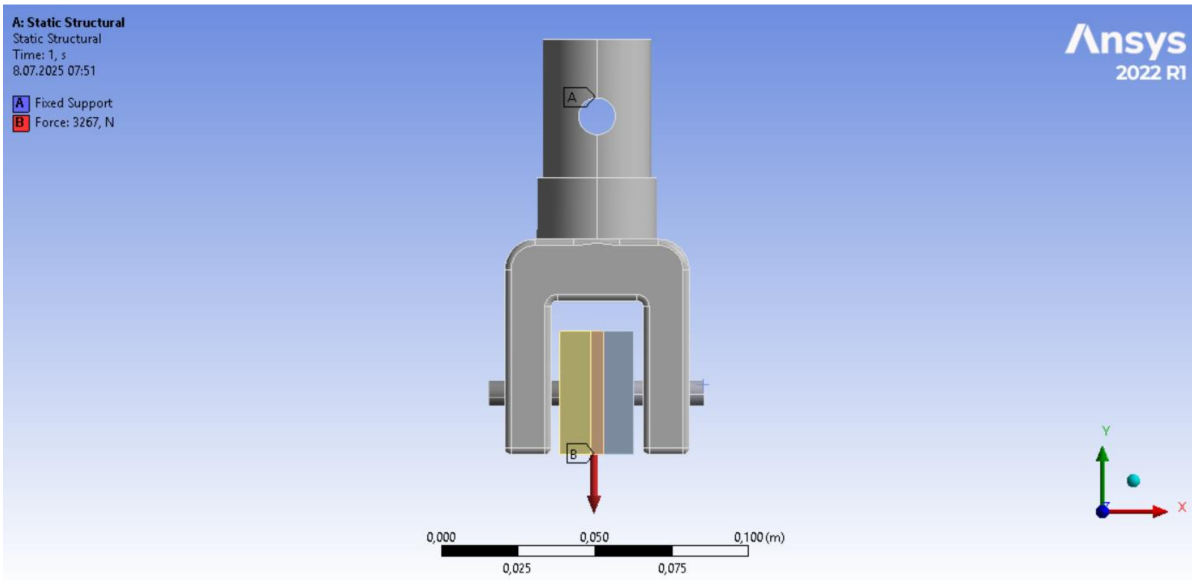

Figure 3.1 Simulation Setup for Screw Side Action Grip

Also generated mesh of the grip and guide pins are shown in **figure 3.2**.

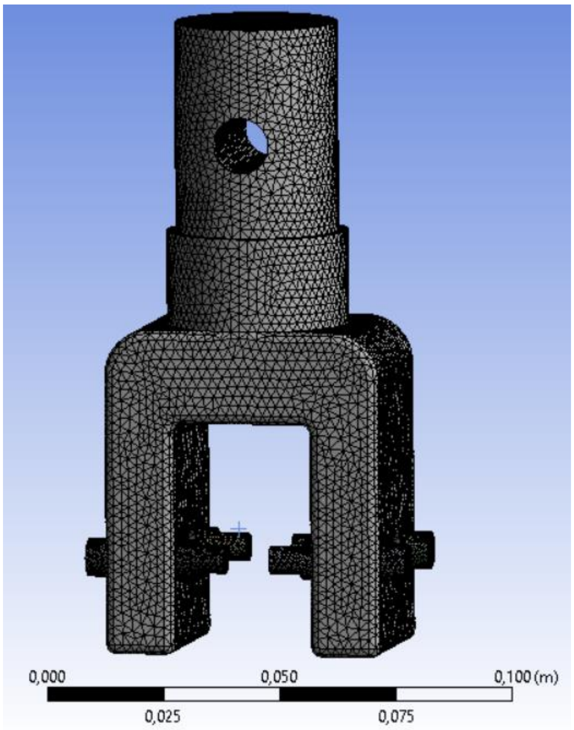

Figure 3.2 Generated Structural Mesh

3.3.2. Stress and Deformation Results

Simulation results **Figure 3.3** indicated that the **maximum von Mises stress** was located at the **guide pin** in agreement with the findings from the analytical model. The maximum stress value was approximately **88.5 MPa**.

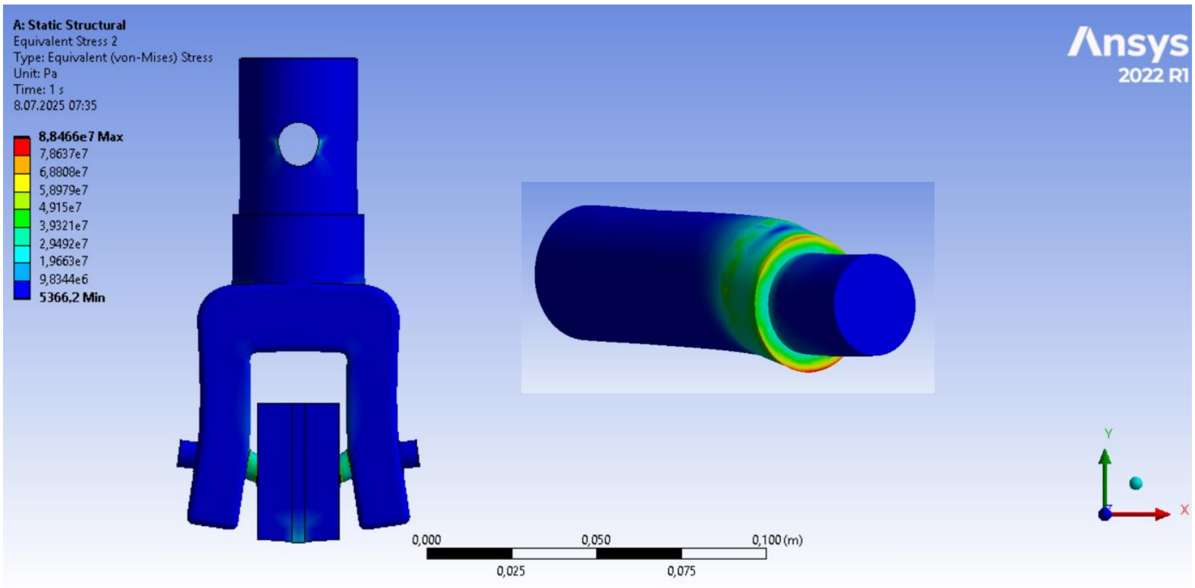

Figure 3.3 Maximum von Mises Stress on Grip and Guide Pin

3.3.3. Comparison with Analytical Calculations

The results obtained from the finite element analysis (FEA) showed a slightly higher von Mises stress compared to the values calculated analytically. While the analytical approach estimated the maximum stress at approximately **86 MPa**, the simulation reported a peak stress of **88.5 MPa** near the jaw-body connection region.

This discrepancy can primarily be attributed to the presence of stress concentration effects, which were not accounted for in analytical calculations. At the region where the guide pin engages with the clamping body, a sudden change in diameter exists. The transition between the larger and smaller diameters of the pin lacks a fillet radius, resulting in a sharp geometric discontinuity. This abrupt change in geometry creates a localized increase in stress, commonly referred to as a stress riser.

Furthermore, the analytical model assumed idealized loading conditions with uniform force distribution and omitted secondary effects such as contact pressure, geometric notching, and local deformation behavior. The finite element model, on the other hand, inherently captures these complexities due to its spatial resolution and material interaction modeling, which naturally leads to slightly more conservative results.

Despite this variation, the results from both approaches remain in reasonable agreement, and the grip design remains structurally safe under the expected loading conditions. The simulation serves as a valuable complement to the analytical analysis by highlighting areas of potential concern, particularly around transitions and connections where detailed stress analysis is essential.

4. COST ANALYSIS

A detailed cost analysis was conducted to assess the economic feasibility of the screw side action grip designed for the Shimadzu AGS-X Universal Testing Machine. The total cost accounts for raw material procurement, machining processes, assembly efforts, and test specimen acquisition. All operations were carried out with support from ERSİN MAKİNE and under academic supervision.

4.1. Material Costs

AISI 304 Stainless Steel (Raw Material):

The primary components, including the body, jaw blocks, and guide pins, were machined from 60×60 mm and 20×60 mm AISI 304 stainless steel stock. The total cost of the raw material purchased from a local supplier amounted to approximately **2,000 TL**

Fasteners and Consumables:

M8 Allen-head bolts, washers, lubricants, and other minor assembly parts were used during construction. These were sourced from standard hardware suppliers and incurred a total cost of **120 TL**.

Test Specimens:

In the test procedure, only 3d printed PLA materials were used. Totally 4 printed test specimens were used. Total cost of the materials are **40 TL**.

4.2. Manufacturing Costs

The fabrication of the grip system involved:

- CNC turning and milling of body, jaws, and pins
- Thread cutting and surface finishing
- Manual fitting and alignment trials on Shimadzu AGS-X

With the industrial support of **ERSİN MAKİNE**, the production took approximately 20–25 effective hours of machining and manual labor. Based on standard machining and workshop rates, the estimated manufacturing cost is 12000 TL, including tool usage, labor, and overheads.

4.3. Time Expenditure

Project planning, design, production, and testing spanned over several weeks. The approximate timeline is outlined in Table 4.1

Table 0-1 Timeline of Project

Phase	Estimated Duration
Design and CAD Modelling	1 week
Structural Analysis & Optimization	1 week
Manufacturing and Fitment Trials	2 weeks
Test Setup and Execution	1 week
Data Analysis and Documentation	2 week
Total Project Time	**~7 weeks**

4.4. Summary of Project Costs

Table 4.2 provides a breakdown of the total project expenditure, covering all major stages from material procurement to final testing. The **overall project cost was approximately 14200 TL**, which is considerably lower than the cost of comparable commercial grip systems available on the market. Commercial mechanical grips with similar capacity and design features typically range between **20,000 to 40,000 TL**, depending on manufacturer and specification.

Table 0-2 Summary of Costs

Item	Estimated Cost (TL)
Stainless Steel Raw Material	2000 TL
Manufacturing (CNC + Manual)	12000 TL
Purchased Samples	200 TL (approx.)
Total Estimated Cost	**14200 TL**

4.5. Remarks

It is important to note that the total project cost presented in the previous sections reflects only the direct, traceable expenses associated with material procurement, manufacturing operations, and testing activities. However, certain **indirect or incidental costs**—such as transportation of raw materials, energy consumption, administrative coordination, and time invested in project planning during the preliminary phases—have not been explicitly included in this calculation. These elements, although relatively minor in isolation, could cumulatively increase the overall cost margin by an estimated 5–10% depending on project scale and logistical constraints.

Furthermore, the **machining and assembly operations** were performed with the generous support of **ERSİN MAKİNE**, which provided access to CNC equipment, workshop facilities, and technical supervision **free of charge**. In a commercial setting, the absence of such collaboration would likely result in significantly higher manufacturing costs due to hourly machine rates, labor charges, and tooling expenses.

These considerations suggest that the reported project cost represents a **best-case scenario** under collaborative academic–industrial conditions. In future applications or scaled production efforts, a more detailed life-cycle cost analysis including overhead, logistics, and maintenance considerations would be necessary to ensure accurate budgeting and resource allocation.

5. TEST SETUP AND PROCEDURE

This section describes the experimental setup, specimen preparation, and the testing methodology used to evaluate the performance of the custom-designed screw side action grip. The primary objective of the testing phase was to assess the grip's ability to securely hold flat specimens during axial tensile loading and ensure alignment with standard testing protocols.

5.1. Test Equipment

All mechanical tests were conducted using a **Shimadzu AGS-X Universal Testing Machine** equipped with a **50 kN load cell**. The AGS-X system allows precise control over crosshead movement and load application and is fully compatible with various grips and extensometers. The **TrapeziumX software platform** was used for real-time data acquisition, force-displacement tracking, and post-processing analysis. The tensile tests were conducted at a constant crosshead displacement rate of 10 mm/min, in accordance with standardized testing procedures, and were performed under controlled laboratory ambient conditions.

5.2. Test Specimen Details

A total of four test specimens were prepared using **Polylactic Acid (PLA)**, a biodegradable thermoplastic commonly used in additive manufacturing due to its dimensional stability and ease of processing. All specimens were fabricated using **Fused Deposition Modeling (FDM)** with **100% infill density**, ensuring maximum internal cohesion for tensile testing purposes.

The specimen geometry was selected in accordance with the **ASTM D638 standard**, which outlines the dimensional specifications and testing protocols for tensile testing of plastic materials. The standard ensures consistent and comparable results by defining gauge lengths, shoulder transitions, and end tab configurations suited for polymer behavior under tensile loads.

To evaluate the effect of printing orientation on mechanical performance, two specimens were printed in horizontal orientation (XY), and two were printed vertically (Z). This allowed for a comparative investigation of the anisotropic mechanical properties of FDM-printed PLA, particularly related to interlayer adhesion and load-bearing capacity.

Figure 5.1 illustrates the PLA specimens after fabrication, showing both horizontal and vertical orientations prior to testing.

Figure 3.4 **Printed Test Specimens**

The material used in the test specimens was Polylactic Acid (PLA), a biodegradable thermoplastic commonly used in fused deposition modeling (FDM) due to its low melting point, dimensional accuracy, and ease of printing. However, it is important to emphasize that the mechanical properties of 3D-printed PLA parts are highly dependent on a number of variables, including:

- Filament quality and storage conditions (humidity, exposure to UV, etc.),
- Printing parameters such as layer height, print temperature, and infill density,
- Build orientation and nozzle speed,
- Ambient environmental conditions during printing and testing.

Due to the sensitivity of PLA to environmental and process variations, direct comparison of the test results obtained in this study with those found in the literature may not yield meaningful conclusions.

In this context, the results obtained from the experimental tests conducted in this project are considered unique to the production method, environmental conditions, and material batch used, and are not intended to be generalized beyond the specific setup and methodology applied.

5.3. Mounting Procedure

Prior to testing, both the upper and lower jaws of the screw side action grip were manually opened to accommodate the PLA specimen. The specimen was carefully centered and inserted between the grip faces to ensure axial alignment and minimize eccentric loading.

Manual clamping was performed, and care was taken to apply uniform torque on both sides of the grip to achieve symmetric clamping pressure.

Tensile tests were conducted using the Shimadzu AGS-X 50 kN Universal Testing Machine. The machine was configured in displacement control mode with a constant crosshead speed of 10 mm/min, as per ASTM D638 recommendations for Type I plastic specimens.

5.4. Test Execution

All tests were carried out under **ambient laboratory conditions**, and the machine was zeroed before each run to eliminate preload effects. The data acquisition system recorded force and displacement in real-time, allowing for the generation of stress-strain curves for each specimen.

Testing continued until the complete failure of the specimen occurred. Any noise, slipping, or unexpected displacement was monitored and logged for further evaluation.

5.5. Post-Test Steps

After each test, the broken specimen was carefully removed from the grips. The following post-test steps were applied:

- **Visual inspection** of fracture surfaces was conducted to classify failure modes (brittle, ductile, or layer delamination).

- Residual plastic particles and debris were cleaned from the grip surfaces to prevent surface contamination in subsequent tests.
- Dimensional measurements of the failed gauge sections were taken for correlation with strain data.
- The test data was exported for post-processing and was later used in comparative performance analysis of the grip mechanism.

Any deformation or wear on the grip surfaces was also examined and recorded to evaluate the long-term usability and mechanical integrity of the grip under repetitive testing conditions.

6. RESULT OF TENSILE TESTING

This section summarizes the results obtained from tensile tests performed on various specimens using both the screw side action grip and the conventional wedge grip. The evaluation focuses on the grips' ability to prevent slippage, maintain uniform stress distribution, and their influence on failure modes. All tests were conducted under standardized laboratory conditions with the Shimadzu AGS-X universal testing machine.

6.1. Test 1-Vertical Printed PLA (Screw Side Action Grip)

The load-displacement curve obtained from the tensile test is shown in **Figure 6.1**. The objective was to evaluate the mechanical behavior of the vertically printed PLA under axial tensile loading and to observe the effectiveness of the screw side action grip in preventing slippage.

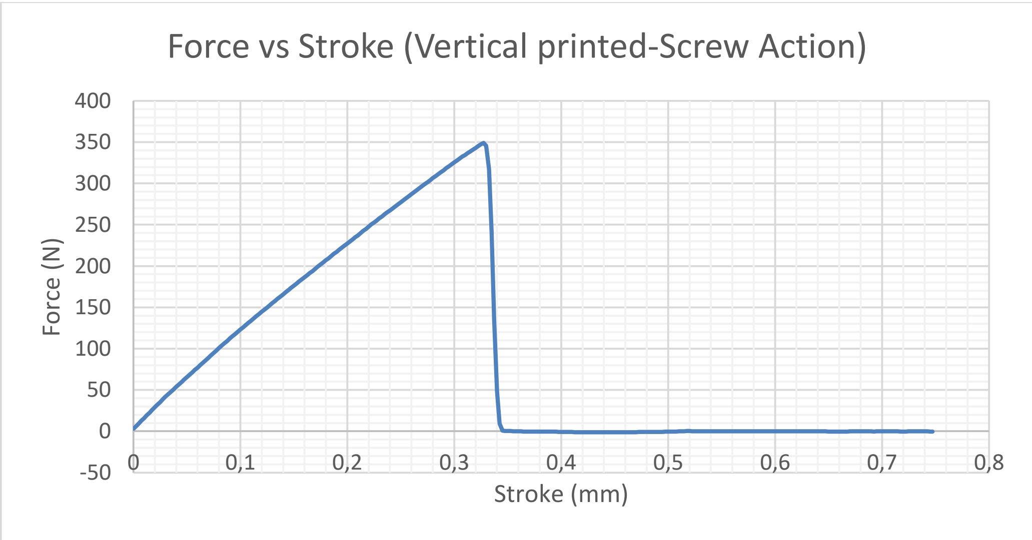

Figure 3.5 Force vs Stroke Curve of Vertical Printed PLA

The graph exhibits a distinct linear region up to approximately **0.33 mm** of stroke, during which the applied force increases steadily, reaching a **maximum value of ~350 N**. This linear behavior represents the **elastic deformation phase** of the material, consistent with **Hooke's law**, where the strain is proportional to the applied stress.

Following the peak load, the force drops sharply to near-zero values, indicating a **brittle**

fracture of the specimen. The abrupt nature of this decline suggests that the failure was not due to slippage but rather due to **material rupture**. In FDM-printed PLA specimens, especially those printed vertically, such sudden failure is common due to weak **inter-layer bonding**, which becomes the primary failure mode under tensile stress.

Post-fracture, the curve shows a low and inconsistent force profile between 0.33 mm and 0.8 mm, likely resulting from minor residual movements in the machine and elastic recovery in the system components after specimen failure. No structural load-bearing capacity remains beyond the failure point.

The stress-strain curve of the vertically printed PLA specimen, presented in **Figure 6.2**, demonstrates the material's mechanical behavior under axial tensile loading. The specimen exhibited a linear elastic response up to a strain of approximately 0.12%, corresponding to a maximum tensile stress of around 27 MPa. This indicates the elastic limit of the material, beyond which brittle failure occurred abruptly.

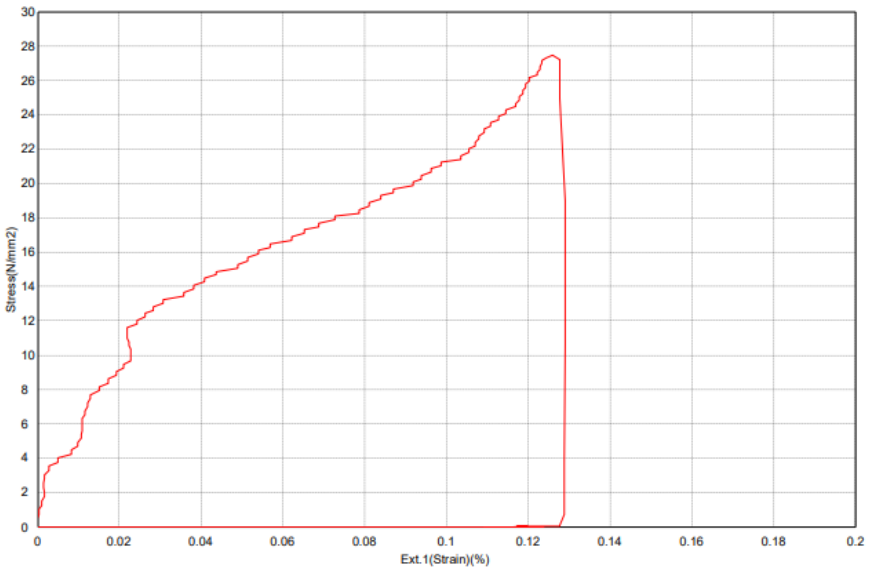

Figure 3.6 Stress Strain Curve of PLA (Vertical Printed- Screw Action)

The sudden drop in stress following the peak value confirms that the specimen fractured without any significant plastic deformation, characteristic of FDM-printed PLA in the vertical orientation due to weak interlayer bonding. The grip successfully prevented any slippage during the test, as evidenced by the clean and sudden failure and the absence of irregularities in the force-displacement data.

6.2. Test 2-Horizontal Printed PLA (Screw Side Action Grip)

The force-stroke curve of the horizontally printed PLA specimen is presented in Figure 6.3. The curve shows a continuous, slightly curved increase in force that becomes steeper as the stroke progresses, reaching a peak at approximately 0.8 mm. After reaching this maximum load which is nearly 850 N, the force rapidly decreases to near zero by 1.2 mm stroke, indicating sudden failure.

Figure 3.7 Force vs Stroke (Horizontal Printed – Screw Action)

This behavior reflects the material's elastic and early plastic deformation phases, followed by abrupt fracture. Compared to the vertical specimen, the horizontal print exhibited a higher peak force, which can be attributed to stronger interlayer adhesion inherent in this print orientation.

The rapid post-peak drop confirms a brittle failure mode, while the smooth increase before fracture indicates stable gripping by the screw side action grip, with no evidence of slippage or premature failure caused by grip instability.

Figure 6.4 illustrates the stress-strain curve obtained from the tensile test of the horizontally printed PLA specimen using the screw side action grip.

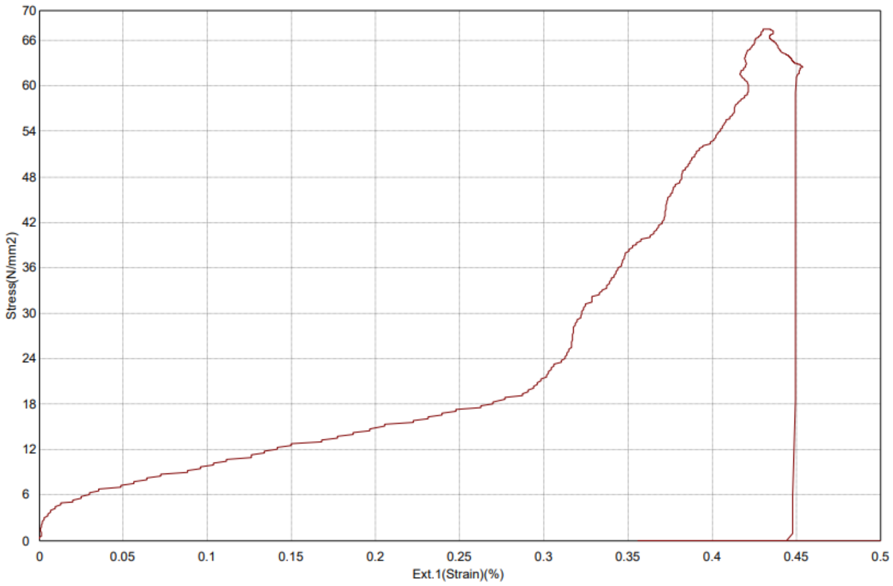

Figure 3.8 Stress Strain Curve (Horizontal Printed – Screw Action)

Initially, the stress increases gradually with strain, reflecting the elastic deformation region where the material responds linearly to the applied load. As strain progresses, the curve steepens, showing an accelerated increase in stress, which suggests the onset of strain hardening typical of thermoplastic polymers.

The maximum stress reached in this test is significantly higher compared to the vertical specimen, consistent with the improved interlayer bonding associated with the horizontal printing orientation. The curve continues to a strain of approximately 0.5%, at which point fracture occurs, marking the ultimate tensile strength of the specimen.

6.3. Test 3-Vertical Printed PLA (Wedge Grip)

The force-stroke curve for the vertically printed PLA specimen tested using a conventional wedge grip is presented in **Figure 6.5**. The plotted line exhibits a gradual increase in force up to approximately 0.39 mm of stroke, at which point it nears its peak value. Immediately following this point, the force drops steeply and abruptly to near-zero levels by 0.4 mm of stroke, remaining near zero for the remainder of the displacement range.

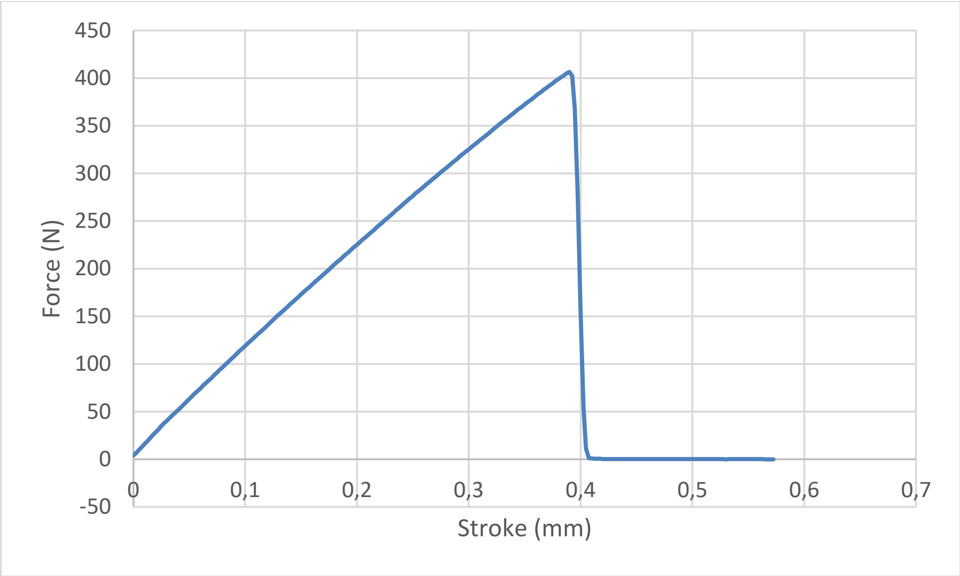

Figure 3.9 Force vs Stroke (Vertical Printed -Wedge Grip)

Figure 6.6 reveals an irregular progression in the stress-strain behavior of the vertically printed PLA specimen tested with a wedge grip. Initially, the strain increases steadily alongside stress, reaching approximately 0.1% strain at a stress level of around 8 MPa. This stage corresponds to the elastic deformation phase of the material.

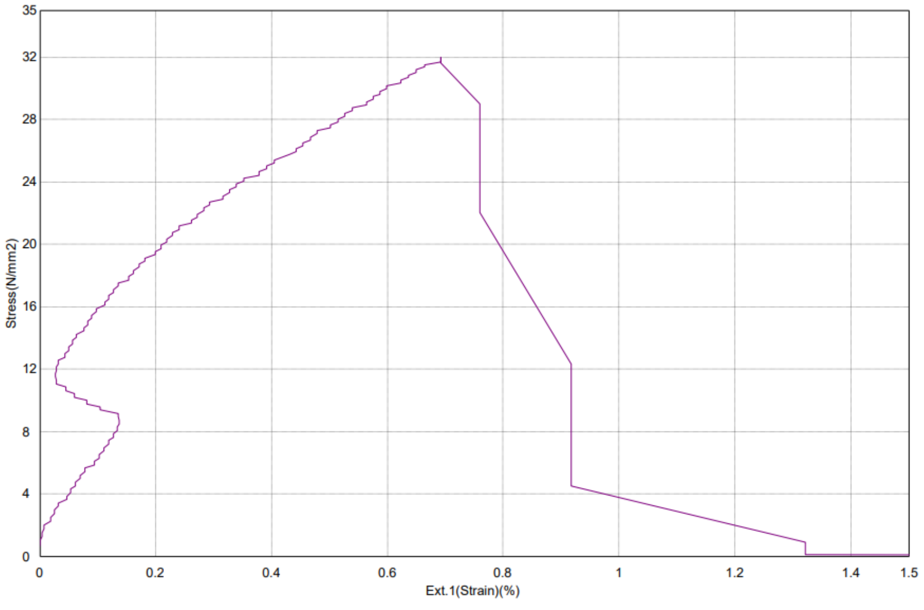

Figure 3.10 Stress Strain Curve (Vertical Printed – Wedge Grip)

However, following this point, an unexpected decrease in the recorded strain is observed while the stress also begins to decline. Such a reversal is atypical in standard tensile testing and may be attributed to experimental artifacts, such as minor slippage of the specimen within the grip or loss of contact between the extensometer and the gauge section. These issues are commonly associated with limitations of conventional wedge grips, particularly when testing materials with low interlayer adhesion like vertically printed PLA. Subsequently, the strain begins to increase once more, reaching a maximum of approximately 0.7% at 32 MPa.

6.4. Test 4- Horizontal Printed PLA (Wedge Grip)

Figure 6.7 shows the force-stroke behavior of the horizontally printed PLA specimen tested using a wedge grip. The force increases linearly up to 0.82 mm stroke, reaching a maximum of approximately 880 N. After this point, the force slightly decreases to around 810 N at 0.88 mm, and then drops abruptly to zero, indicating sudden fractures. The stable increase prior to failure suggests that the specimen was adequately gripped, and no slippage occurred during the loading phase.

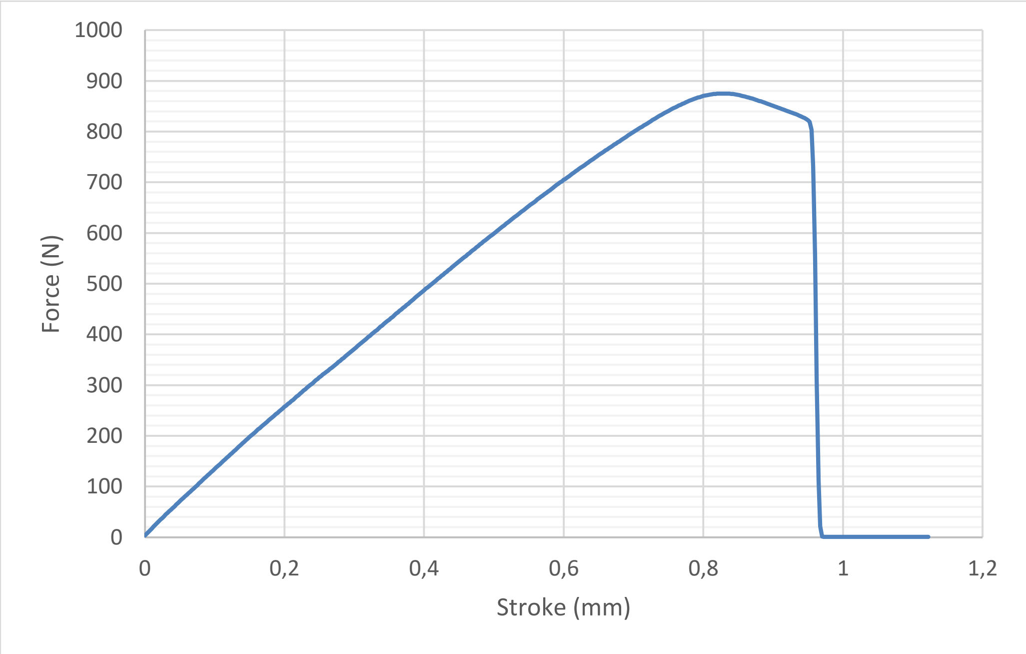

Figure 3.11 Force vs Stroke (Horizontal Printed -Wedge Grip)

The horizontal orientation provided improved mechanical performance due to better interlayer bonding. Compared to vertical specimens, the failure occurred at a higher load and after a longer displacement, reflecting increased structural integrity.

The corresponding stress-strain curve is presented in Figure 6.8. A well-defined linear region is observed up to approximately 2.5% strain, with the stress reaching 880 MPa. Following this, the stress gradually decreases to around 65 MPa at 3.6% strain, after which a sudden drop occurs, marking complete failure.

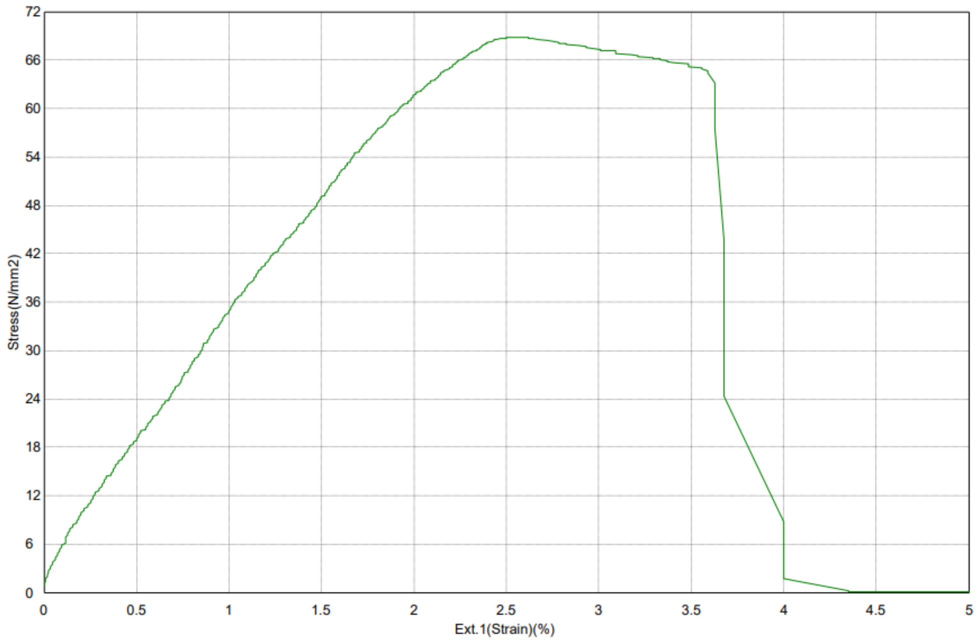

Figure 3.12 Stress Strain Curve (Horizontal Printed- Wedge Grip)

In contrast to the vertical specimen tested with the same grip type, the stress-strain behavior here appears more consistent and reliable. The wedge grip functioned adequately in this case, likely due to the specimen's higher layer cohesion and resistance to slippage under axial loading.

6.5. General Interpretation

The experimental results reveal meaningful distinctions between the gripping systems and specimen orientations, offering insights into both the mechanical performance of the PLA material and the effectiveness of the grip designs under tensile loading.

One of the most prominent findings relates to the **influence of printing orientation**. Horizontally printed PLA specimens consistently exhibited higher tensile strength and greater elongation before failure, primarily due to stronger interlayer bonding in the loading direction. In contrast, vertically printed specimens showed lower load capacities and brittle fracture behavior, confirming the mechanical limitations of FDM-produced parts along the Z axis.

A critical aspect of this study was the **comparative performance of the screw side action grip and the wedge grip**. At **lower force levels**, particularly in tests involving vertically printed specimens, the **screw side action grip** demonstrated superior stability and reliability as shown in **Figure 6.9**. The gripping mechanism provided uniform clamping pressure and prevented slippage, resulting in clean, interpretable force-displacement and stress-strain curves. This made it especially effective for testing weaker or more fragile samples, where excessive localized pressure from traditional grips could lead to premature or artificial failure.

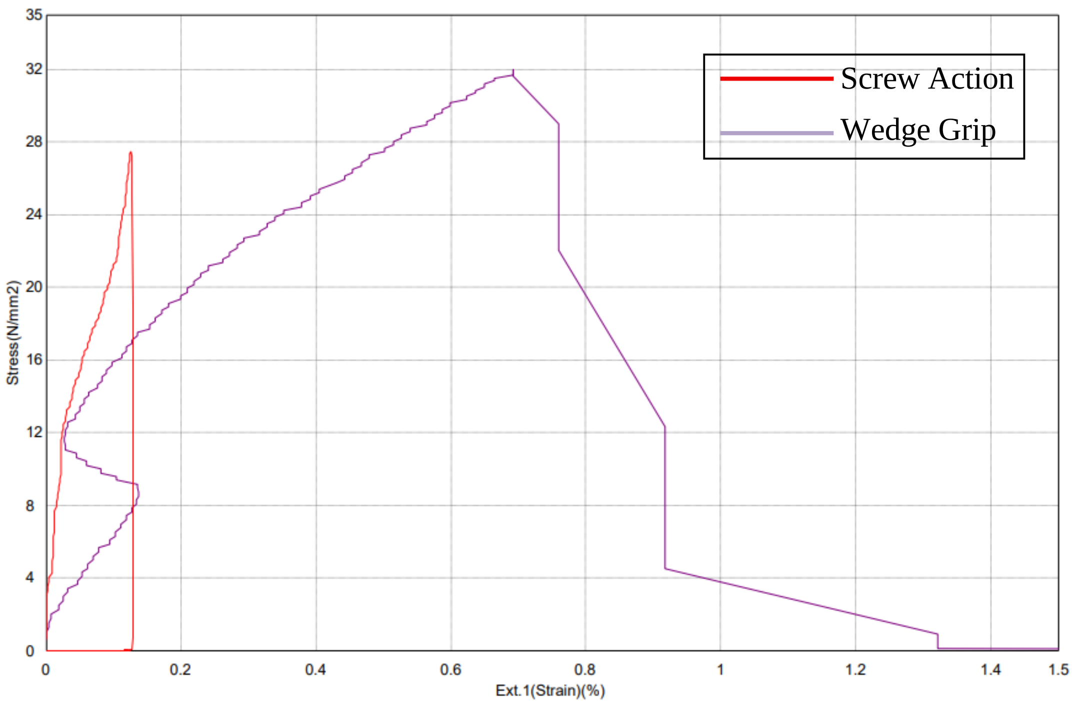

Figure 3.13 Screw action vs Wedge Grip (Low Force Range)

However, in tests involving **higher tensile forces**, especially with **horizontally printed specimens**, the **wedge grip produced more robust and consistent results** as shown in **Figure 6.10**. Its self-tightening mechanism under increasing load provided enhanced grip strength, which became more effective as the force rose. In such cases, the wedge grip was able to maintain stable contact without slippage or deformation of the specimen ends, thereby delivering reliable data up to the point of failure.

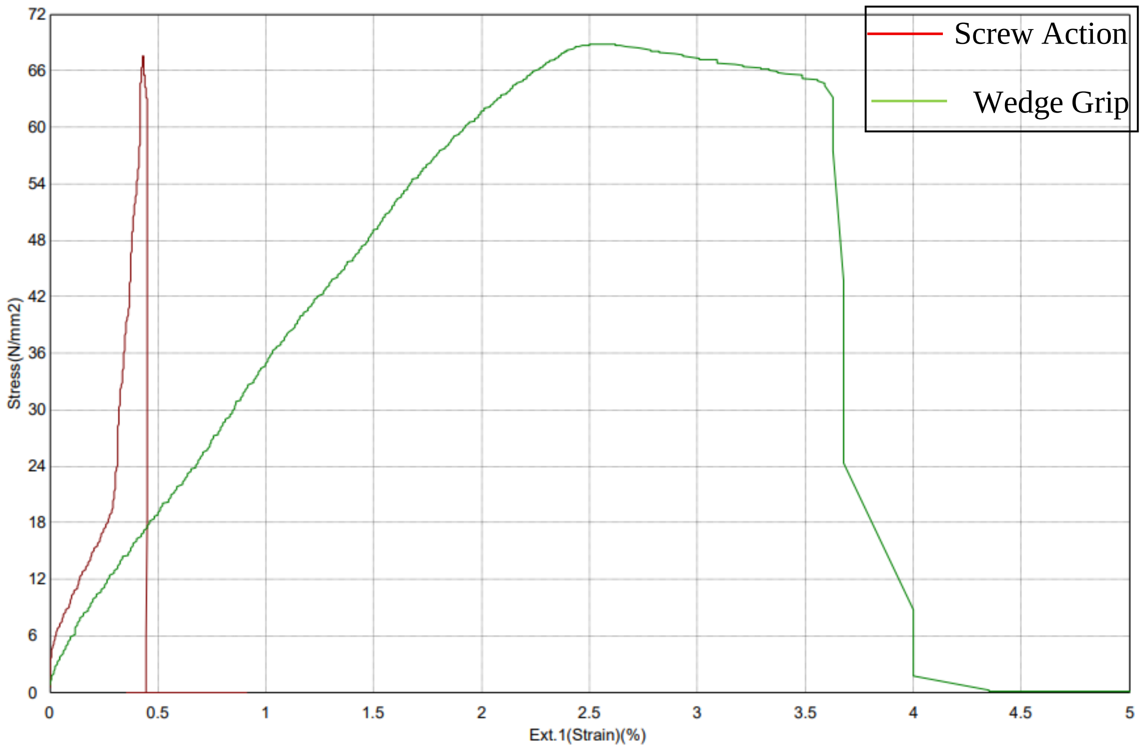

Figure 3.14 Screw action vs Wedge Grip (High Force Range)

In summary, the **screw side action grip is better suited for low-force applications**, such as testing vertically printed or lower-strength materials, where stable alignment and slip prevention are critical. Conversely, for **high-force testing**, the **wedge grip can offer superior performance** due to its self-reinforcing clamping action under load. These observations underline the importance of selecting the appropriate grip type not only based on specimen geometry or material but also on the expected force range during mechanical testing.

7. CONCLUSION AND SUGGESTIONS FOR FUTURE STUDIES

In this study, a screw side action grip was designed and manufactured to be compatible with the Shimadzu AGS-X universal testing machine, with the aim of improving clamping stability and minimizing slippage during tensile testing of low forces. To evaluate its effectiveness, tensile tests were performed on PLA samples fabricated in both vertical and horizontal orientations, and the results were compared with those obtained using a conventional wedge grip.

7.1. Conclusions

The test results showed that both the gripping method and printing orientation have a substantial impact on the mechanical performance of PLA specimens. Horizontally printed samples demonstrated superior tensile properties due to improved interlayer bonding, while vertically printed specimens were more prone to brittle failure, consistent with the anisotropic nature of FDM-printed materials.

The screw side action grip delivered particularly reliable results in low-force applications. It ensured uniform clamping pressure and proper alignment, which was especially beneficial when testing vertically printed specimens with lower structural integrity. The force-stroke and stress-strain curves obtained using this grip were smooth and consistent, indicating stable engagement and absence of slippage.

On the other hand, at higher load levels, the wedge grip exhibited better performance. Its self-locking mechanism responded effectively under increasing tensile force, offering sufficient holding strength during tests on horizontally printed samples. Despite its limitations in low-force scenarios, the wedge grip proved more suitable for high-strength specimens.

Overall, the screw side action grip achieved its intended purpose as a stable and effective alternative for specific testing conditions. While it excels in controlled, low-load applications where slippage is a risk, the wedge grip remains advantageous in tests requiring higher clamping force. The comparative findings underscore the importance of grip selection based on both material characteristics and expected loading conditions.

The screw side action grip designed in this study has demonstrated promising performance, particularly in low to moderate tensile force applications where stability and slip prevention are critical. However, several aspects of the current design present opportunities for further improvement and investigation.

7.2. Suggestions for Future Studies

One area of future development involves enhancing the **ergonomics and usability** of the grip. While the current screw-based tightening mechanism offers effective clamping, its manual operation can be labor-intensive and time-consuming. Alternative handle geometries, such as wing nuts, quick-release levers, or ratcheting mechanisms, may improve user comfort and reduce setup time without compromising clamping force.

Another important direction for future work is the **material selection for grip components**. Exploring the use of high-strength or surface-hardened materials for the jaw faces, such as tool steel or carbide coatings, could improve wear resistance and allow the grip to withstand higher forces. Additionally, using lightweight alloys or composite housings may reduce the overall weight of the device, enhancing maneuverability in laboratory environments.

To further improve **axial alignment and load distribution**, different jaw geometries and alignment aids could be introduced. Concepts such as self-centering v-blocks, spring-loaded contact faces, or guide pins may help minimize eccentric loading and improve the repeatability of test results, especially for delicate or non-standard specimen geometries.

Moreover, adapting the screw side action grip for use with a **broader range of materials and test types**—such as rubbers, fiber-reinforced composites, or even soft biological materials—would enhance its versatility. For each of these material classes, appropriate surface textures, jaw coatings, or pressure regulation mechanisms may need to be considered to avoid localized damage while maintaining sufficient grip.

Lastly, experimental evaluation of the grip under **dynamic and long-term loading conditions** (e.g., fatigue, creep, or thermal cycling) could provide deeper insights into its mechanical durability and long-term stability. These studies would be valuable for establishing design standards and supporting potential commercialization or modular upgrades of the system.

In summary, the screw side action grip provides a solid foundation for laboratory tensile testing, and with targeted design enhancements, its functionality, ergonomics, and applicability can be further extended to meet a wider range of experimental requirements.

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APPENDICES

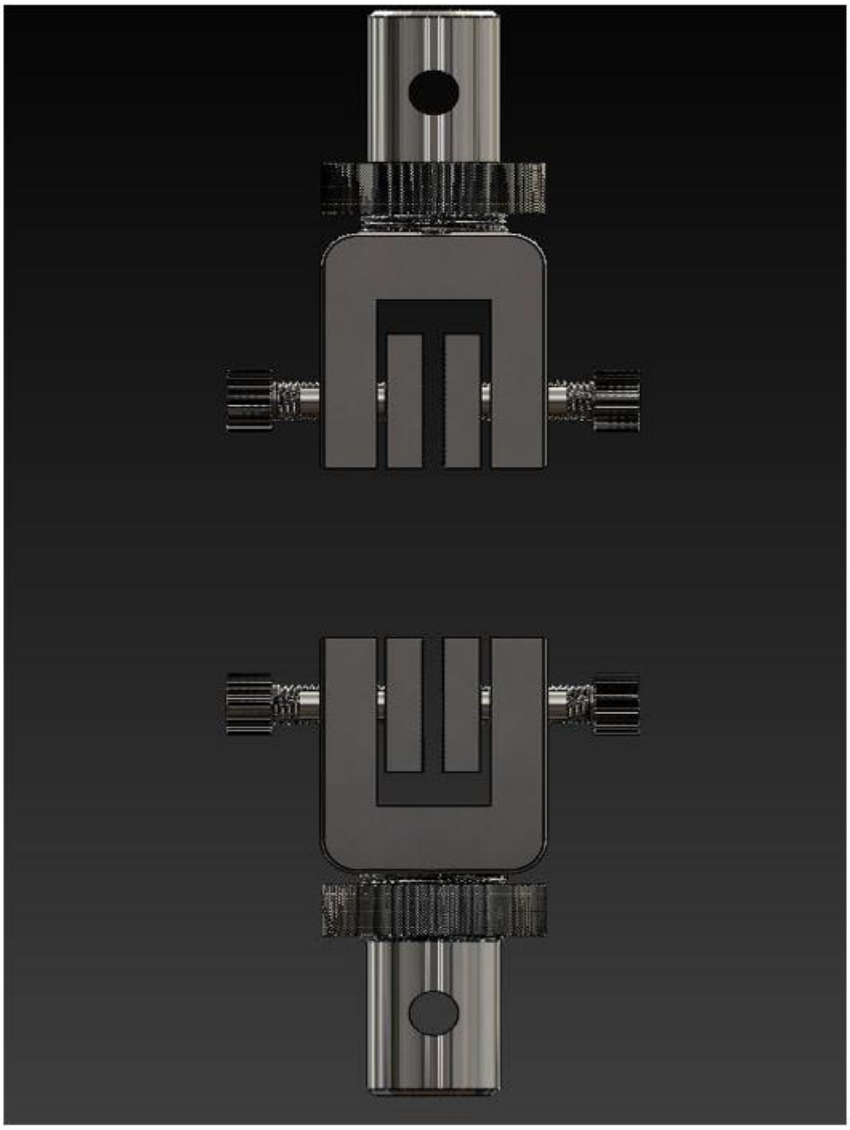

Figure A 1 Assembly of Screw Side Action Grip

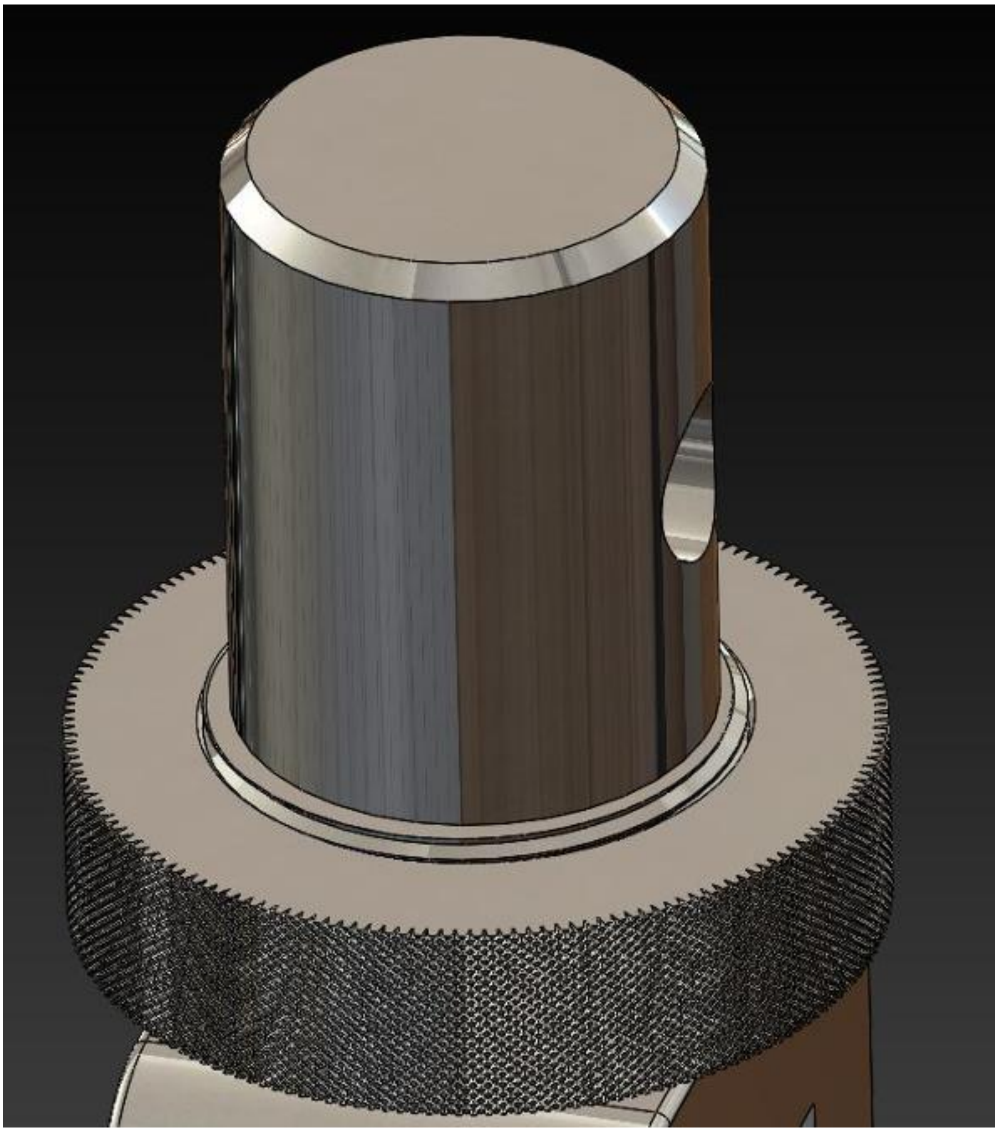

Figure A 2 Connector part and knurled surface

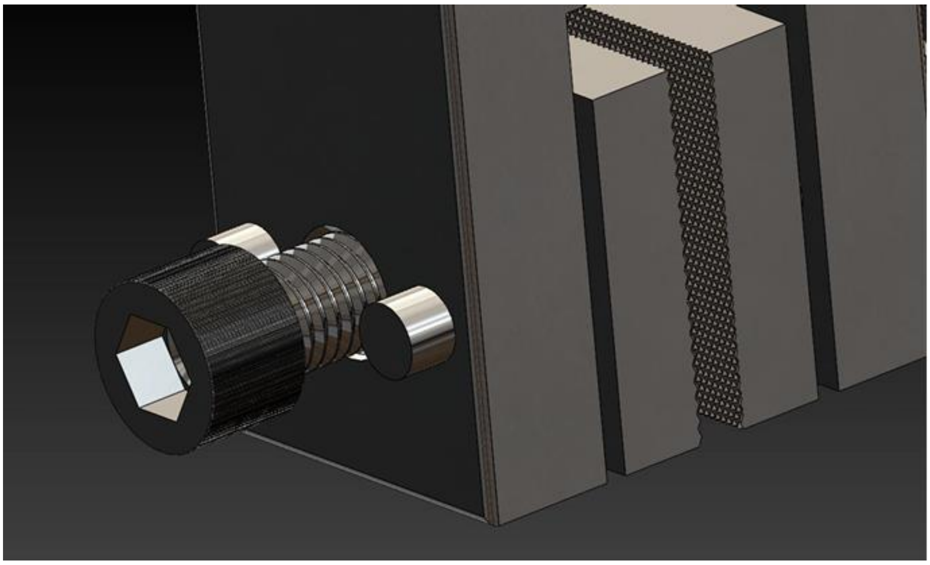

Figure A 3 Guide pins and knurled jaw

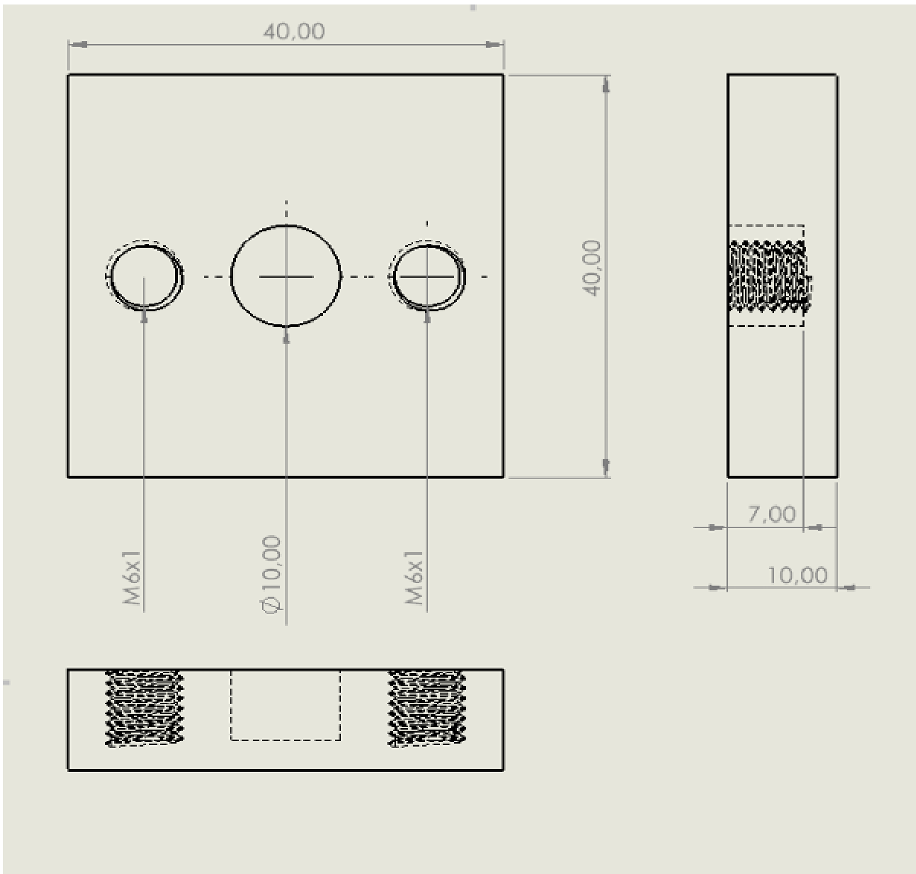

Figure A 4 Jaw Dimensions

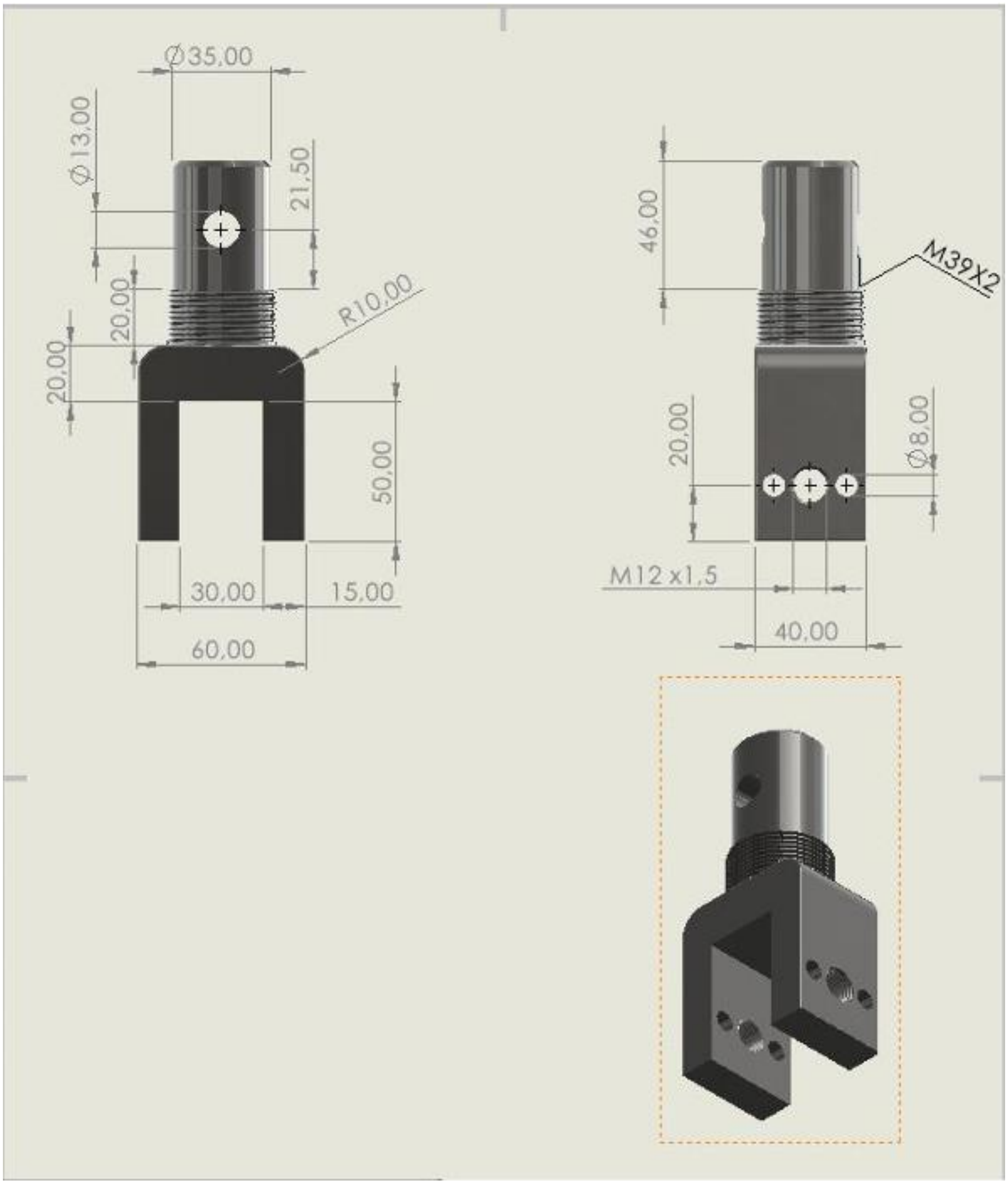

Figure A 5 Grip Dimensions

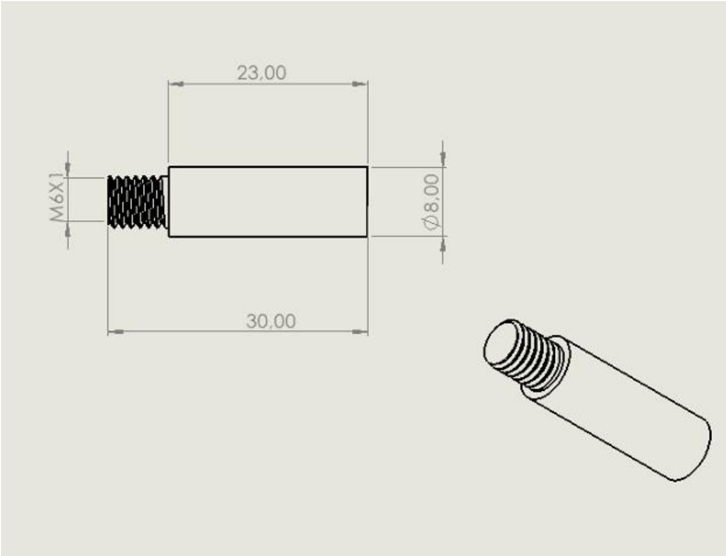

Figure A 6 Guide pin dimensions

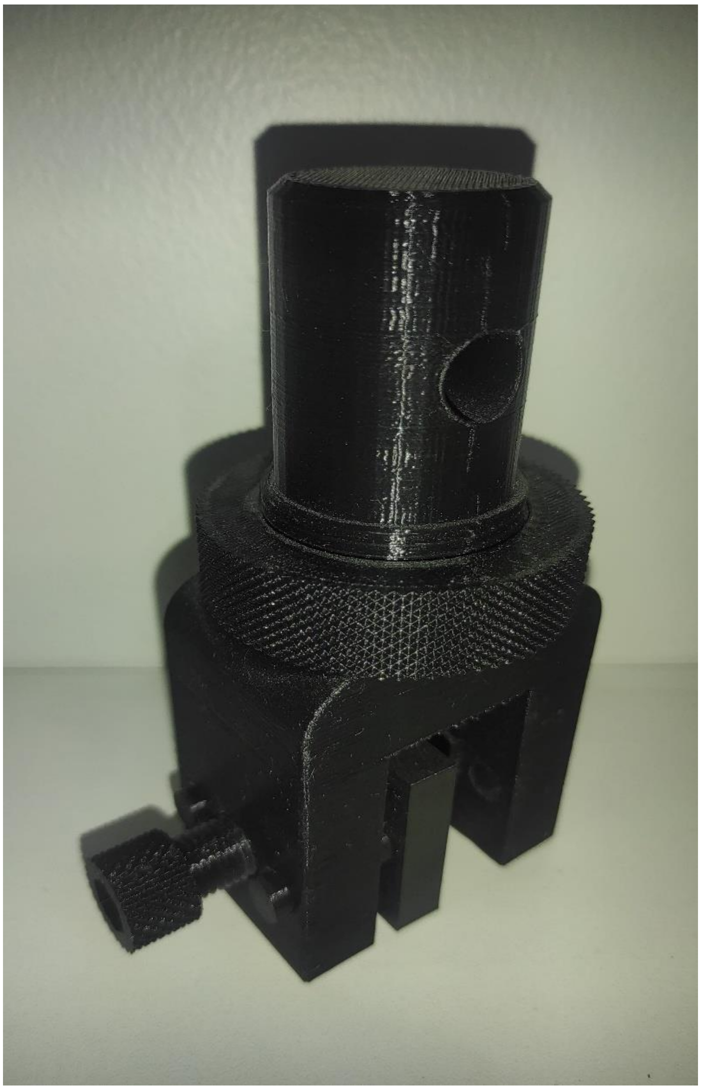

Figure A 7 Prototype of the grip

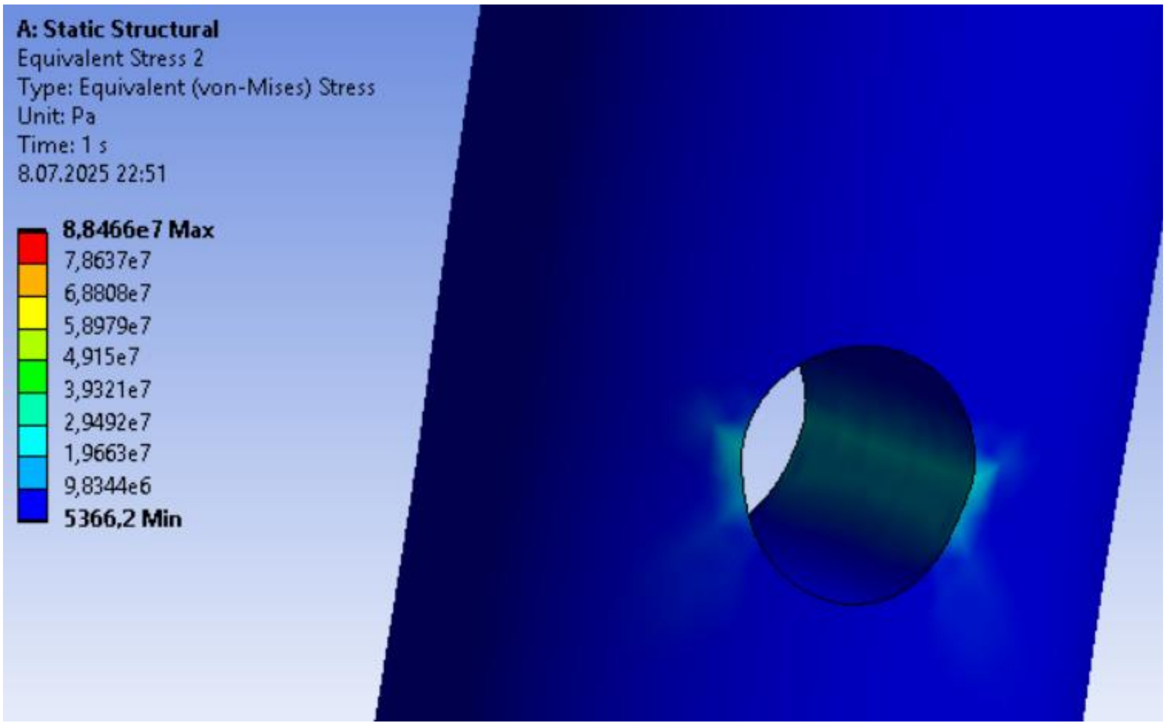

Figure A 8 Stress concentration over the connector pin hole

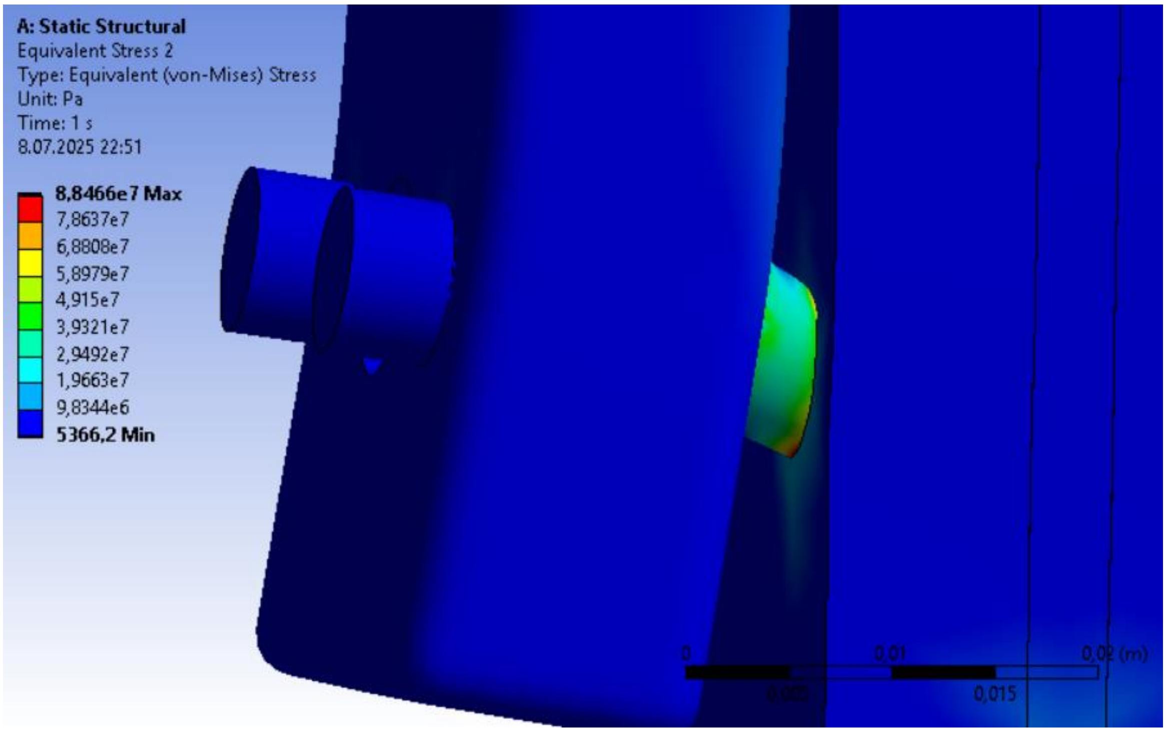

Figure A 9 von Misses Stresses on the guide pin

Figure A 10 Test setup

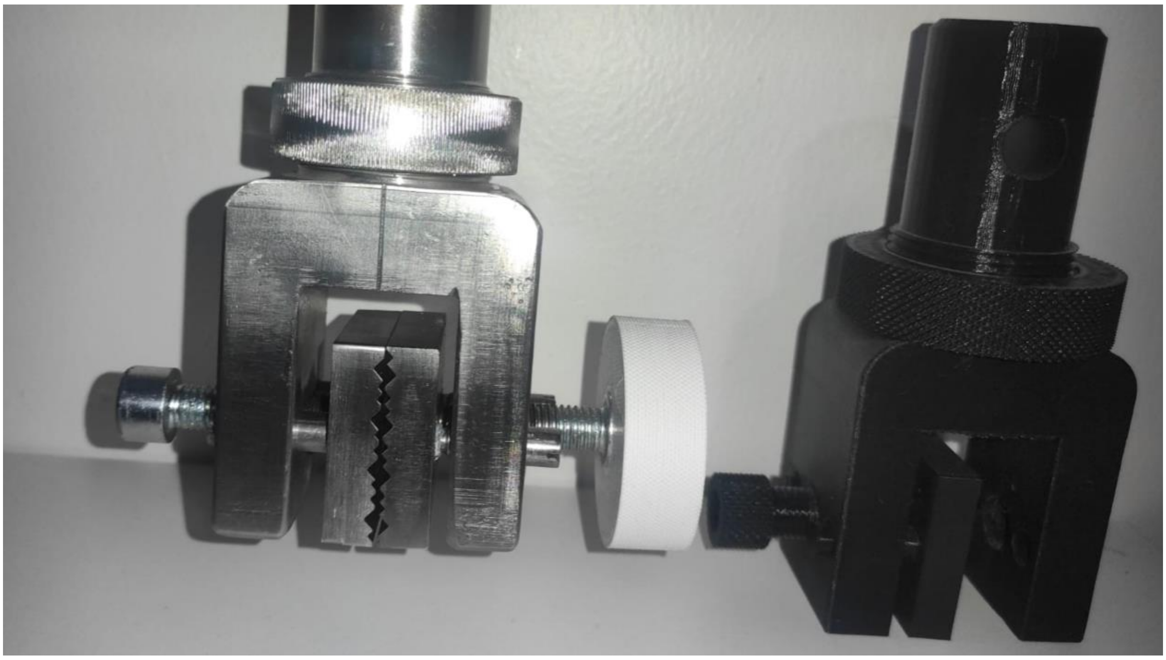

Figure A 11 Future improvement

Figure A 12 Test specimen deformations

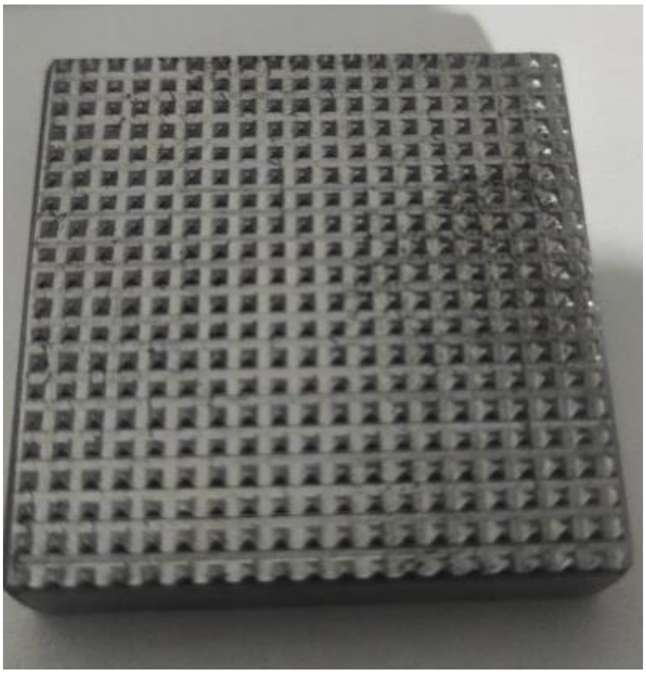

Figure A 13 Knurled contact surface

Raw testing data is available as soft copy.