THESIS

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Mechanical engineering

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Hungarian University of Agriculture and Life Science

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Mechanical Engineering Course

Designing of experiment and test of preloaded bolted joints. Analysis of the effect of bolts with different yield strengths on the coefficients of friction.

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INSTITUTE OF TECHNOLOGY MECHANICAL ENGINEERING (MSC)
Technical development specialization

THESIS

worksheet for

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(MSc) student

Entitled:

Analysis of the effect of bolts with different yield strengths on the coefficients of friction.

Task description:

This experiment aimed to provide reliable data for coefficients of friction for M10 bolts and washers, considering various yield strengths. The methodology involved precise measurement setups, data collection, and careful analysis of the results. These findings are valuable for understanding the behavior of these mechanical fasteners under different conditions, which can have implications for engineering and design applications.

Department: Mechanical Engineering

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Approved **Received**

(head of department) (host course leader) (student)

As an independent consultant of the author of this thesis, I hereby declare that the student took part in the planned consultations.

Gödöllő, 25 October 2023.

(Consultant)

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1. Introduction:

Bolted joints came into prominence in the eighteenth century, and have been used in various applications including bolted. When a rail joint bolt is used to connect components, it provides a high clamp force that is known as pretension or bolt preload Numerous mechanical designs use bolted joints as their principal method of fastening. Despite their widespread use, bolted joints have complex behavior. Numerous factors influence every aspect of the typical bolted joint, from the initial torque and preloading to the final stresses carried by the bolt. The actual hundreds of characteristics that must be taken into account to characterize joint behavior make it difficult for even experienced users to make the right choice, combination, and usage of the variables. These variables become even more crucial when it is taken into account that a failed bolted joint would typically have a negative impact on the system's functionality or safety.[1]

Also, Threaded fasteners are used widely due to their strength, simplicity, and ease of assembling and disassembling. Preloading threaded connections and tightening bolts increase the bearing capacity and dependability of those connections. Preload of threaded connections might be considerable or minimal due to nut factor uncertainty, which has an impact on construction reliability and safety. Preload affects how well a structure can support weight, and too little preload can cause bolts to yield, loosen, or even break. Small preloads result in lateral or clearance movement between connected elements, which is dangerous for normal machine operation. For pre-tightening threaded connections, it is essential to understand the relationship between torque and preload. To control the preload when tightening threaded connections, the torque moment technique is frequently used in engineering applications.[2]

The threaded fastener and the elements that need to be connected are the main elements of the bolted cross. By threading the fastener into a nut or into threads that have been threaded into one of the pieces, the bolted joint creates an initial clamping force on the joint. The riveted pieces are kept in contact and under pressure the entire time the joint is in use thanks to this preload.[3]

2. Literature review:

2.1. Basics of bolted joints:

Bolted joints are temporary fasteners that are used to connect elements/components to form mechanical structures. They are used in modern engineering structures and machine design due to the following advantages: high load-carrying capacity, reliability, ease of assembly and disassembly of structures/machine components (especially for maintenance purposes)[4], relatively low cost, and efficient manufacturing process.

Bolted joints consist of a bolt, nut, and sometimes a washer, which can be considered as the parts of the clamp members. Bolted joints connect components through applied clamping force provided by the tension in the bolt.[5]

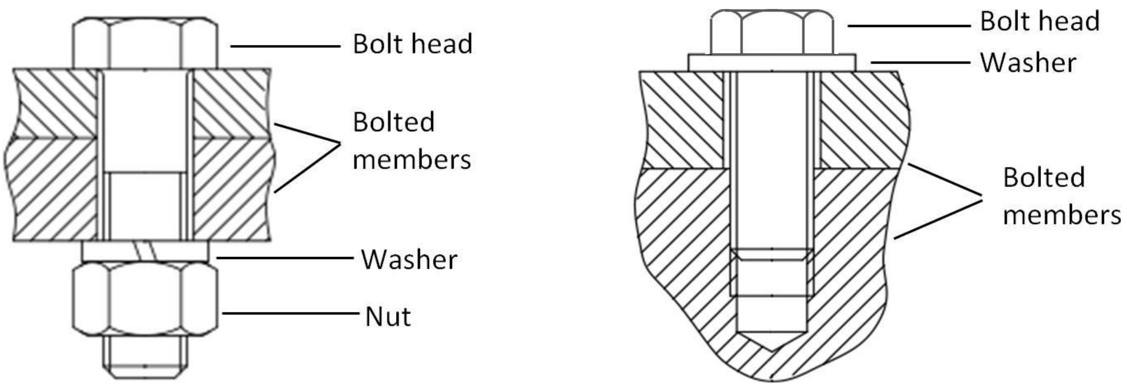


Figure 1 Vertical sectional view of bolted joint and screw joint.

The purpose of a bolt or group of bolts in all tensile and in most shear joints is to create a clamping force between two or more things, which we'll call joint members. In some shear joints, the bolts act, instead, primarily as shear pins, but even here some bolt tension and the clamping force are useful, if for no other reason than to retain the nuts[6].

• Bolted joints are connectors that affect Stiffness (as they are not rigid) and Vibration, Damping, and Stability.

• Bolted Joints are needed for disassembly, for maximum benefits are obtained when they are preloaded and threads can plastically deform

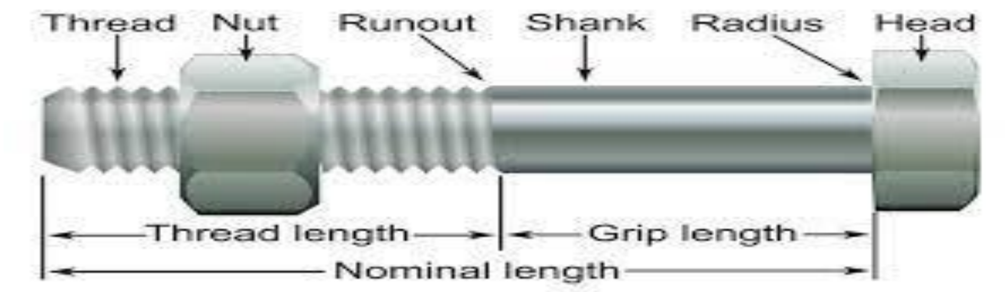


Figure 2 Examples of bolt and nut.

- Two commonly used bolts are partially and fully threaded

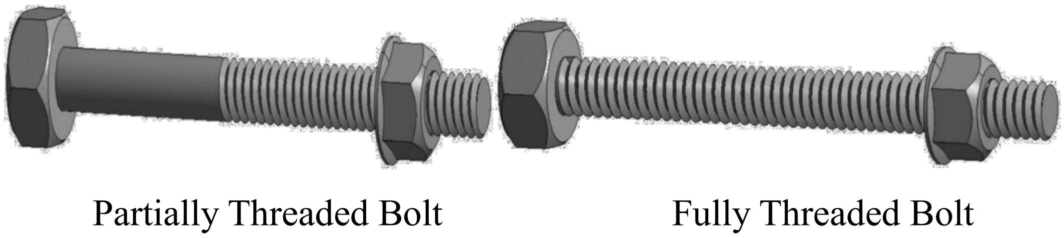


Figure 3 partially and fully threaded bolt.

2.2. Bolt Heads:

- Hexagon-head bolts are one of the most common for engineering applications, usually shut and for heavy duty[7], W is usually about 1.5 times the nominal diameter and bolt length L is measured from below the head

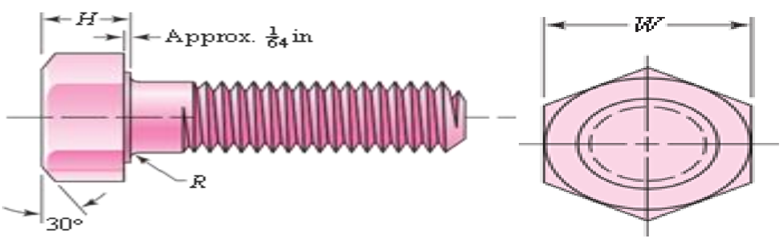


Figure 4 Hexagon-head bolts.

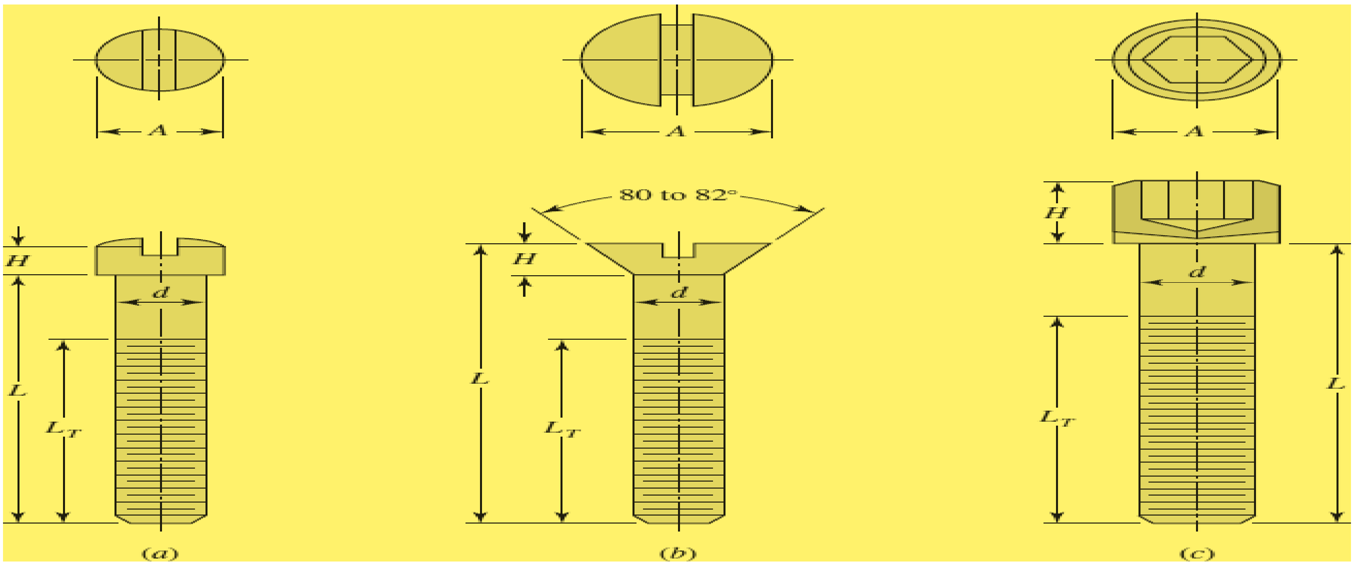


Figure 5 Socket head cap screw.

- Machine screws are Usually smaller sizes v Slotted or Philips head common they are threaded all the way[8]:

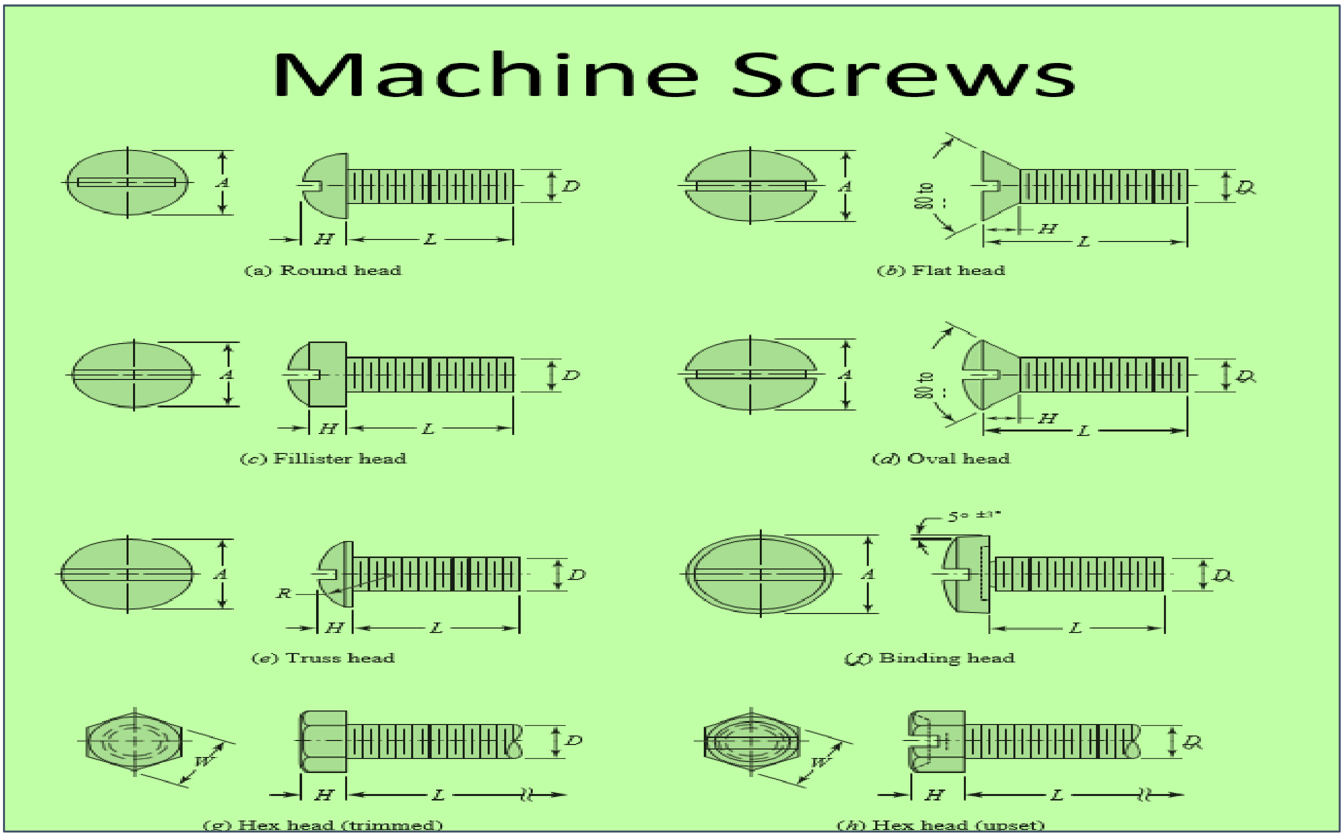


Figure 6 types of machine screws.

Depending on the direction of the external loads or forces operating on the joint, there are two types of bolted joints. The joint is referred to as being loaded in tension and is known as a tension or tensile joint if the direction of the forces acting on it is roughly parallel to the axis of the bolt.[9]

The joint is loaded in shear and is known as a shear joint if the line of action of the load is roughly perpendicular to the axis of the bolt.

They are named after the larger of the loads exerted on them, be it tensile or shear, and support combined tensile and shear pressures.

The distinction between tensile and shear joints is important because the two types differ in the way they respond to loads, how they fail, how they are assembled, etc.

2.3. Load acting :

Bolted joints are classified by the loads acting on them. If those loads and forces are in a parallel direction to the axes of the bolts the joint is called a tensile or tension joint.

The bolt's tension needs to be high enough to avoid self-loosening when subjected to vibration, stress, or heat fluctuations. High bolt tension may also reduce the bolt's susceptibility to fatigue (but sometimes more susceptible to stress cracking). However, generally speaking, we want the bolt in a joint loaded in tension to provide as much stress to the joint as the joint components and the bolt can withstand.

When working with tension joints, you should bear in mind two key points.

A device for producing and maintaining a force, the clamping force between joint elements, is firstly the bolt[10].

Second, the strength and stability of that factor greatly influence the behavior and lifespan of the bolted joint, however, the tension in the bolt is the crucial factor in terms of its life and integrity, to succeed we must keep an eye on both the inter-joint clamping force and the bolt tension When the joint is initially assembled, the clamping force on the joint by rotating the nut or the bolt head, bolts are tightened. Of course, this action also induces tension in the bolt; at this point, the tension is typically referred to as preload. when a bolt is tightened, some of the threads may bend plastically, but the majority of the bolt and the joint elements react elastically as the bolt is tightened.

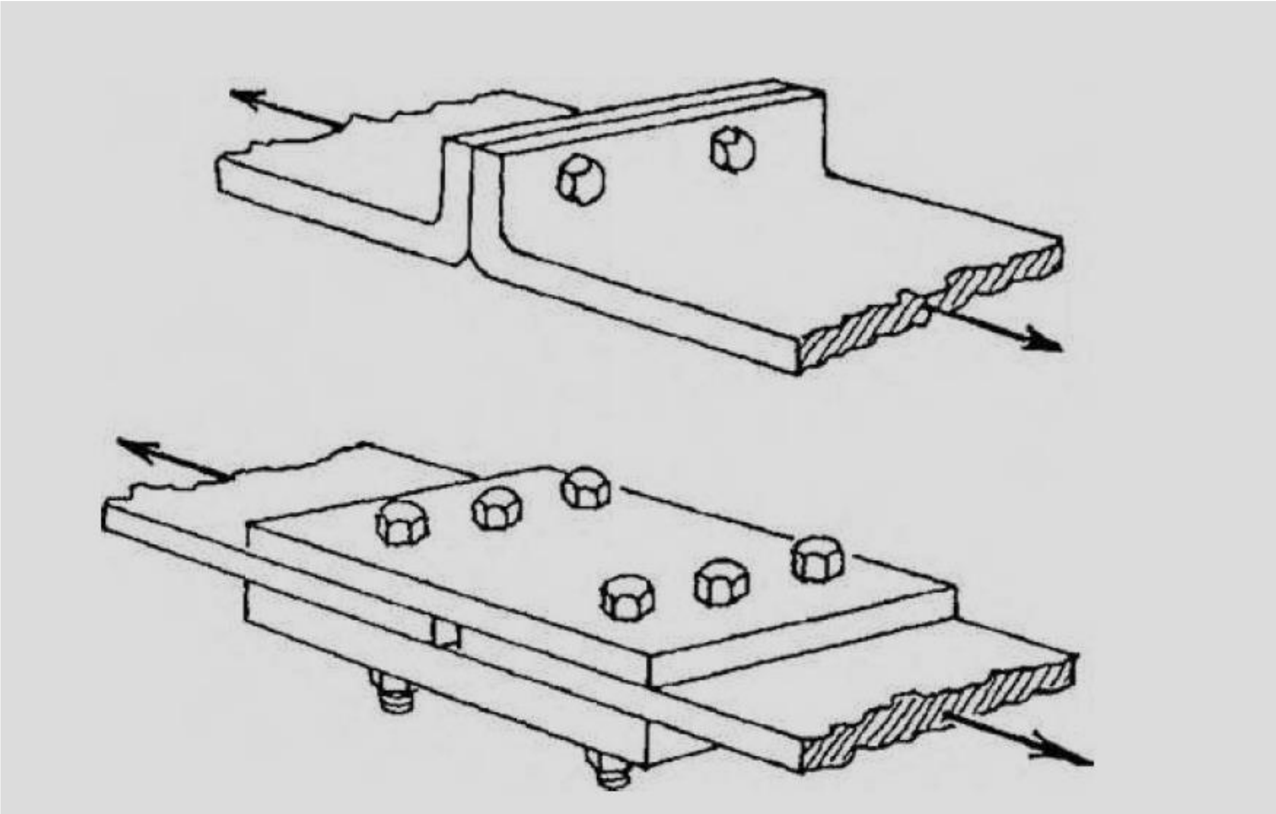


Figure 7 Acting loads on bolted joints.

2.4. Tension joint and shear joint :

We can say in a focused and specific way in points: In a tension joint, the bolt predominantly supports tensile loads that pull the plates apart.[11]

1-Applied loads act along the axis of the bolts.

2-Due external tensile loads, the forces acting through the cross-section of the bolt increase, and the clamping force must be selected to ensure there is no plastic deformation of the bolt. Shear joints experience loads in a direction perpendicular to the axis of the bolt.

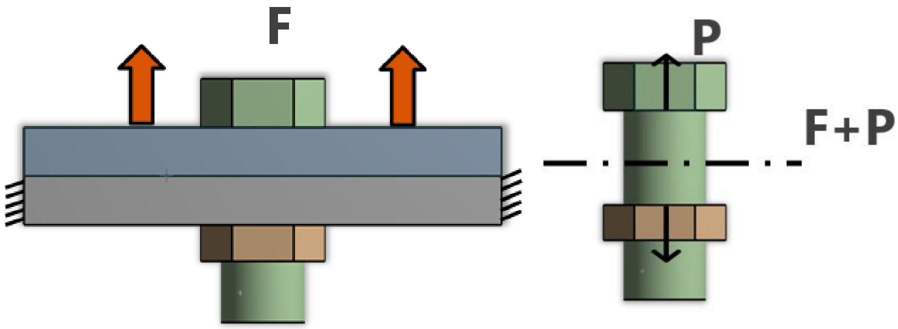


Figure 8 Tension joint load acting on it.

1-Performance depends on the friction between the fastener and the component, as well as the shear strength of the bolt.

2-If the preload is not sufficient to counter the external load, then the component slips and the joint fails, and in some cases, the bolt directly supports the external load, and friction is not needed. Such loads are called bearing loads[12].

Here, preload is not important, and the shear strength of the bold determines the strength of the joint. Partially threaded bolts are suitable for these joints as they offer more stiffness.

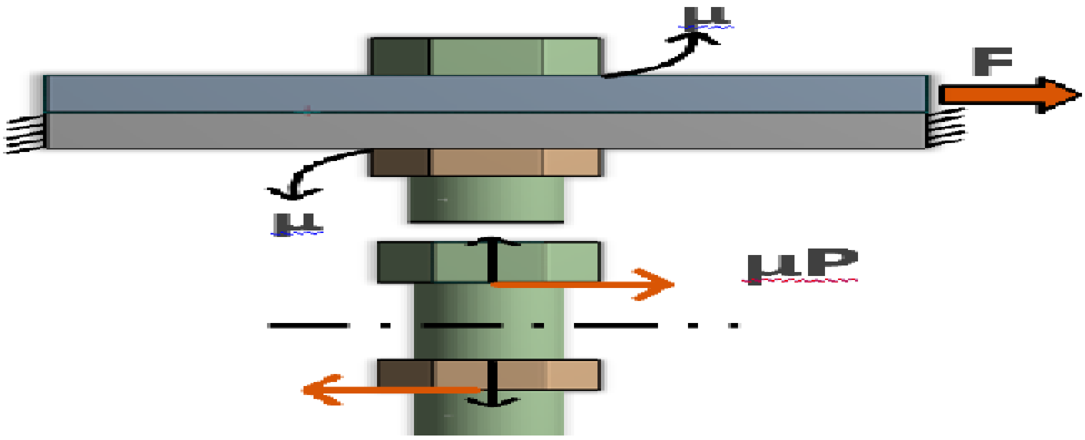


Figure 9 Shear joint force acting on it.

2.5. Thread fasteners:

Threads have been developed in many places in our world, and therefore a large group has been produced subject to many changes and standards. Joseph Whitworth's suggestion of having a 55° (V) thread shape and standard threads per inch for various diameters (based on sample nails from a large number of British workshops) in 1841 became standard practice in Britain in the 1860s. In 1864 in America, William Sellers independently proposed another standard based on a 60°V thread shape and different thread phases for different diameters. Subsequently, it developed into American Standard Coarse Chain (NC) and Fine Chain (NF)[13]. The thread shape had a root and a flat top which made the screw easier to make than the Whitworth standard which had a root and a rounded to about output the same time metric thread standards were adopted in the mainland An international standard metric thread eventually evolved from German and French metric standards based on 60V thread with flat tops and rounded roots[14]

A fastener with a screw thread on one of its parts is referred to as a threaded fastener. The shank and the head make up the bolt. The stem is screwed, either along a portion of it or the entire way from one end to the other. Typically, longer screws are just partially threaded. It is not necessary to thread the screw longer than is required to tighten the joint because doing so will merely increase the cost of the screw.

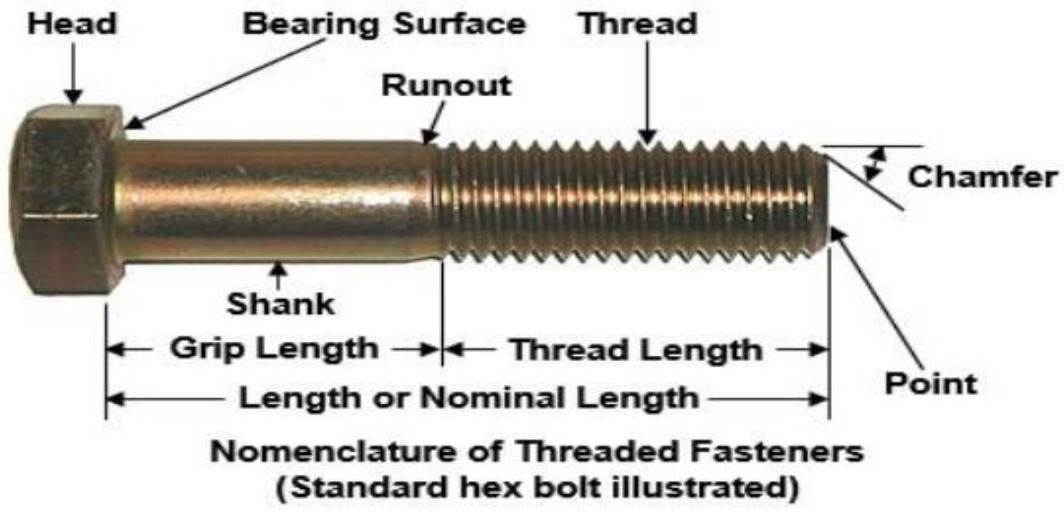


Figure 10 Nomenclature of Threaded Fasteners.

The thread form, which consists of the crest, root, and flanks, is the thread's shape or profile in an axial plane for the length of one pitch of the thread. The crests and roots are at the top and bottom of the threads, respectively, and the flanks connect them. Vee (V) threads, square threads, etc. are examples of thread forms

A screw thread is a continuous projecting helical ridge usually of uniform section either on the external or internal surface of a cylindrical or conical surface

Two uses for threaded screws are power transmission and fastening[15]. Fasteners feature a V-shaped thread profile, where the flanks produce an acute angle at the thread tip, whereas power screws have threads with parallel or nearly parallel flanks. Frictional torque must be reduced for power transmission, which is accomplished by Square, Acme, or Buttress threads.

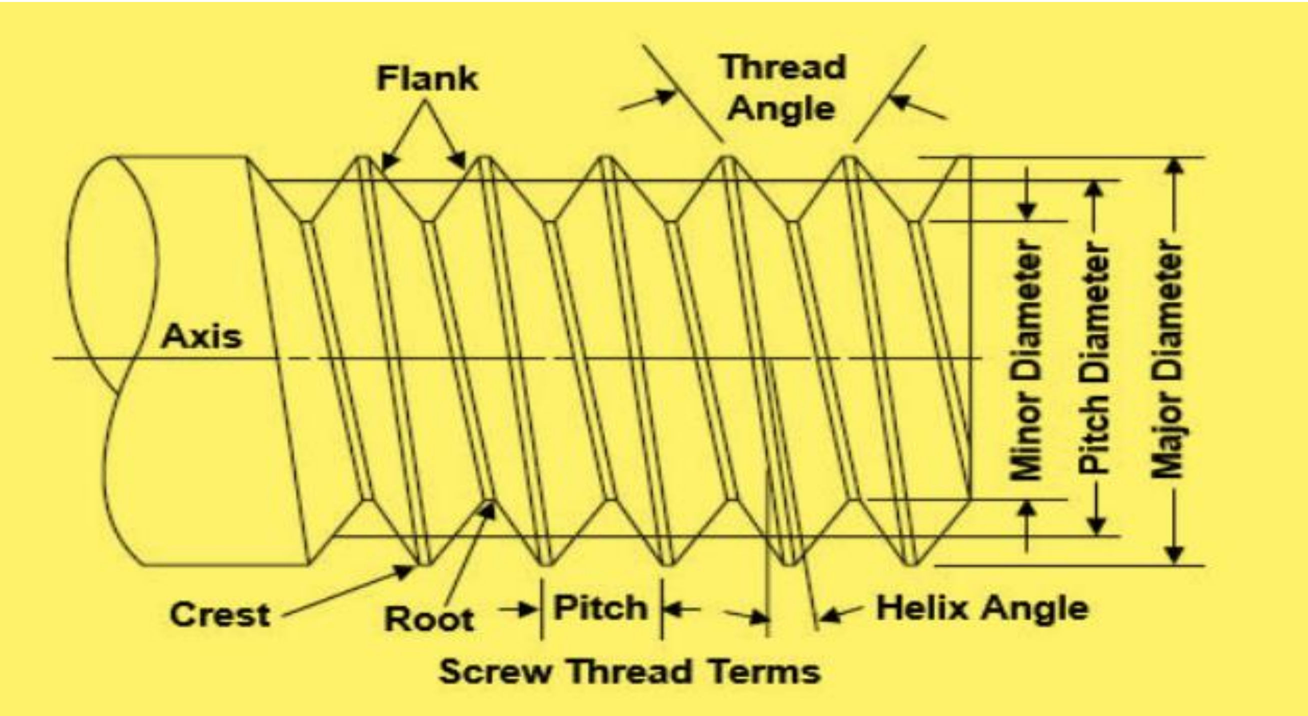


Figure 11 screw thread terms.

For applications involving power transmission, threads with parallel or nearly parallel sides are desired. Specific thread profiles, including Square, Acme, or Buttress threads, are used to satisfy the demand for less frictional torque. The choice of a certain thread design is in line with the desired use, emphasizing the complex interaction between

thread geometry, function, and friction control in a variety of mechanical applications.
The surface of a thread that connects its flanks and is located the furthest from the cylinder or cone from which it projects is called the crest[16].
The surface of a thread known as the root connects the sides of adjacent thread forms and is located next to the cylinder or cones from which the thread is extending.
A helical thread surface's flank is the section that connects the crest and root, which are conceptually two straight lines in an axial plane section.

- The spacing between adjacent thread formations measured parallel to the thread axis is known as pitch which is the reciprocal of N, the metric value for the number of thread forms per inch.
- The greatest diameter is the primary diameter (d) of a screw thread, and the major diameter
- The screw thread's minor (or root) diameter is its smallest diameter. The minor diameter
- The thread angle is the included angle formed by two adjacent flanks in an axial plane.

Mechanical threaded fasteners' behavior is greatly influenced by friction. The threads of these parts contact when they are tightened, creating frictional forces that affect how well they function. Both the preload force attained during tightening and the resistance to loosening over time are impacted by friction. It's an important factor that affects how much torque is needed for effective assembly, how clamping force is distributed, and how self-loosening under dynamic loads is avoided. Engineers carefully analyze friction in threaded fasteners to achieve the ideal preload force for joint integrity while minimizing the risk of excessive friction that could reduce the fastener's functionality or lifespan.[17]
To prevent self-loosening and preserve joint integrity, friction is necessary. But too much friction can impede precise torque-to-tension conversion and result in incorrect preload. The delicate link between friction, torque application, and preload force in threaded fasteners is highlighted by balancing the appropriate amount of friction for consistent and reliable fastening results.

Threaded fasteners, such as bolts are used to transfer load between machine parts, and bolts are utilized. This load gearbox can hold parts together and stop leaks, as in the case of machine flanges, or it can be utilized to transfer power, as in the case of a compressor rod coupled to the piston. The goal of achieving an infinite bolt life is achieved through good design and placement.

When selecting and installing bolts, take into account the following factors:

- The transmitted load's size and direction.
- The rationale behind the pairing.
- The nature, rigidity, and thickness of the connecting materials.

2.6. Bolt work theory

Uneven load distribution across bolt threads Due to material elasticity, loads are concentrated on threads closest to the bearing surface. When the bolt is preloaded during installation, the bolt and junction will deform. Each component's elastic deformation relies on its stiffness. This figure illustrates the bolt and junction[18] deforming elastically. This graphic illustrates that the bolt's elastic deformation is the more significant. When an external load is applied, the bolt load increase is less than the applied load, and therefore improperly preloaded bolts subjected to cyclic stresses may fatigue fracture

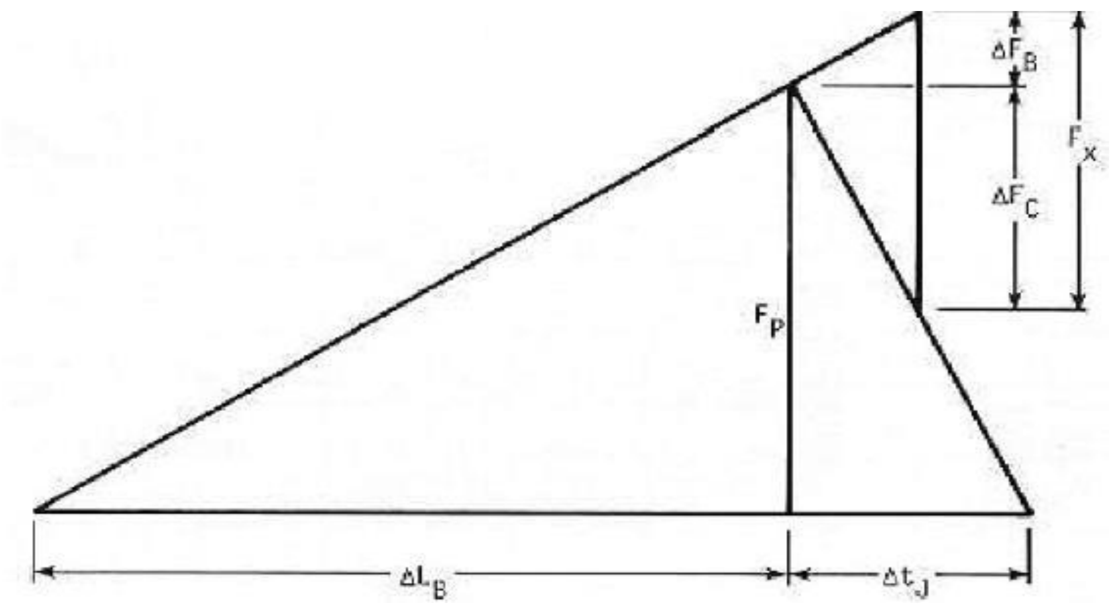


Figure 12 The deformations caused by the preload (Fp) when an external force is applied

2.7. Friction in threaded fasteners

In the field of threaded fasteners, particularly in bolts, friction is a crucial yet complex phenomenon. These inconspicuous parts keep equipment, buildings, and gadgets together, frequently by exerting stresses that exceed the strength of the materials. Beyond merely mechanical interaction, friction in bolted joints affects preload forces, torque-to-tension relationships, and ultimately the structural stability of assemblies.

A bolted joint relies on the tension created by the torque imparted to the bolt as its basic structural component. As the threads of the bolt and the mating surface come into contact, friction enters the picture and resists relative motion. Preload, a crucial component in preserving the integrity of the joint, is created by this contact, which transforms torque into clamping force[19].

The intricate thread profile of bolts and other threaded fasteners considerably increases frictional effects. When tightening, friction forces are heavily influenced by the form and angles of the threads. The threads often have a V-shaped design with the flanks meeting at an acute angle at the crest. With this construction, a self-locking mechanism that can withstand loads and vibrations from outside is guaranteed. Understanding how thread geometry impacts friction is crucial because the precise nature of this angle influences how torque is converted into preload.

When comparing applications for power transmission vs fastening, an intriguing aspect is revealed. Secure clamping with less self-loosening tendencies is necessary for fasteners. Due to the acute angle at the center of the V-shaped thread pattern, stability is promoted in these circumstances.[20]

When comparing applications for power transmission vs fastening, an intriguing aspect is revealed. Secure clamping with less self-loosening tendencies is necessary for fasteners. Because of the acute angle at the thread crest, the V-shaped thread pattern shines under these circumstances. Power transmission applications, on the other hand, demand an effective torque transfer with a minimum amount of frictional losses. In this situation, threads with flanks that are parallel or nearly parallel are preferred to lessen frictional torque and improve energy efficiency.

2.8. Preloaded bolt joints and joint diagram

To understand the mechanics of bolted joints we need to determine how much tightened torque is applied, what the deep meaning of preloaded bolted joint is its behavior with and without external load, and how it affects stiffness and geometry.[21]

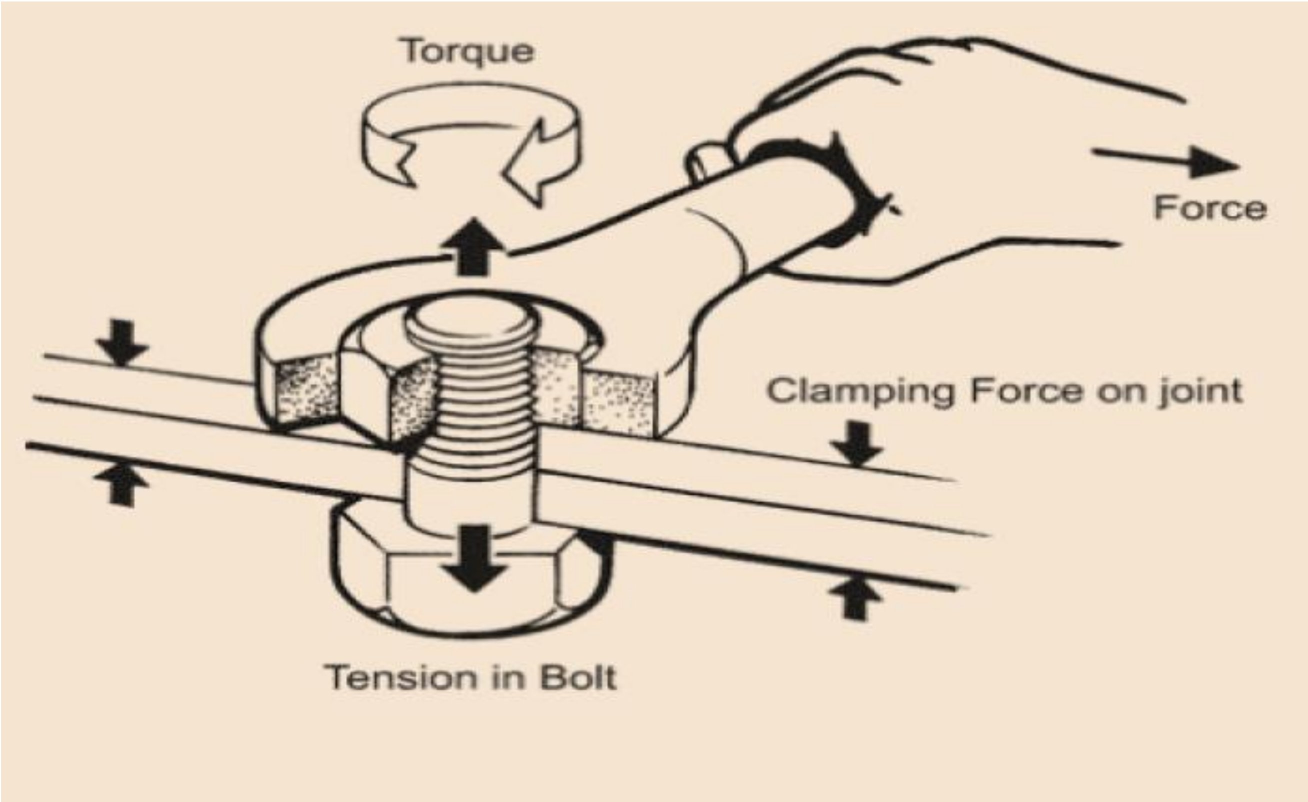


Figure 13 sketch view of forces acting on the bolt.

when applying a tightened torque, the bolt stretches which creates tensile stress on the bolt, this tensile load is known as preload which also creates a compressive force called a clamping force, it seems that all applied load converts to preload but in fact, 10 % only of applied torque converts to useful preload and 50% frictional resistance between joint parts which is the nut and washer or the nut and the joint and the rest 40 % used to counter friction between threads of nut and bolt

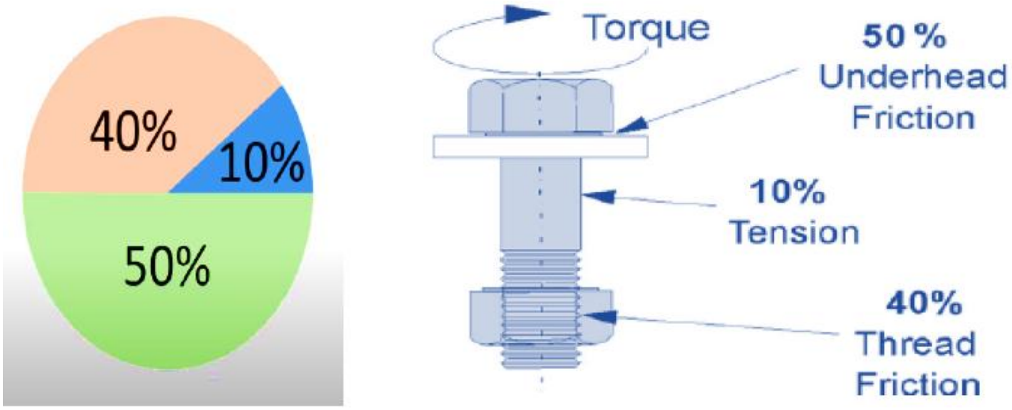


Figure 14 Torque and distribution diagram.

Materials are kept together by applying a compressive force using a bolt and nut together. The screw's and nut's threads combine to exert force on either side of the secured material. The compression produced as the nut is tightened against the bolt is known as bolt preload (or vice-versa).

The purpose of preload is to place the bolted components in compression for improved resistance to either static or cyclic external loads.[22]

In a preloaded bolt, an initial tensile load is created as soon as tightening torque is applied. This moves the bolt head against a clamped component. The bolt head and the thread generate the preload in the bolted joint the more the threaded mating, the more the preload is generated

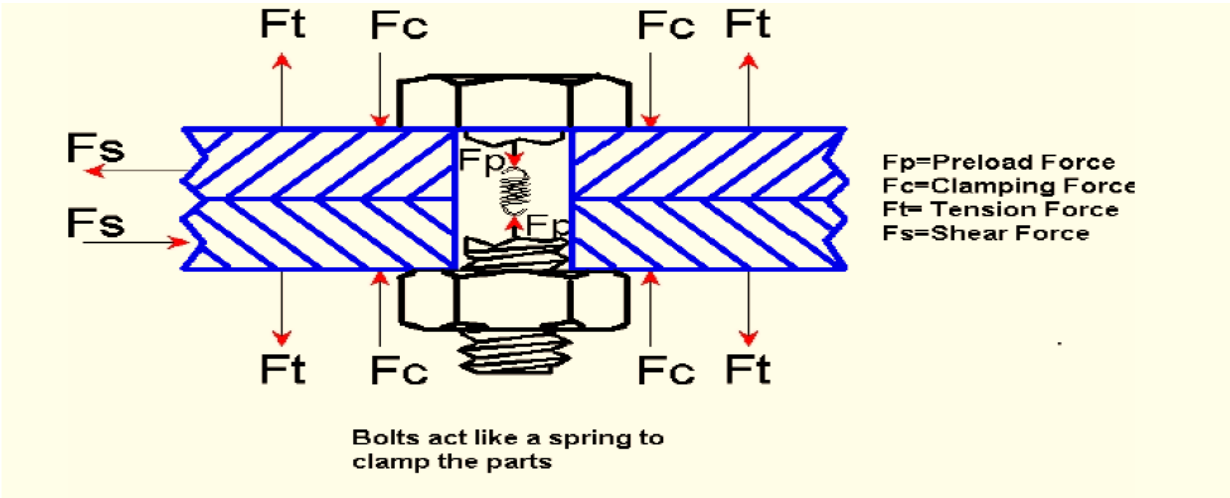


Figure 15 Forces acting on bolt preloaded

Preload creates a force between the bolted joint members so that the shear load can be resisted by friction force

The determination of proper preload depends on the accurate predictions of member stiffness. The geometry and magnitude of the contact pressure at the contact interface are essential in determining the clamping performance of the bolt and associated joint stiffness

Joint diagrams have been produced to better visualize the loading within bolted connections. A joint diagram can be used to show the bolts and the material it clamps' load deflection characteristics. Using joint diagrams can help you understand how a bolted joint withstands an external force and why the bolt cannot withstand the entire force.[23]

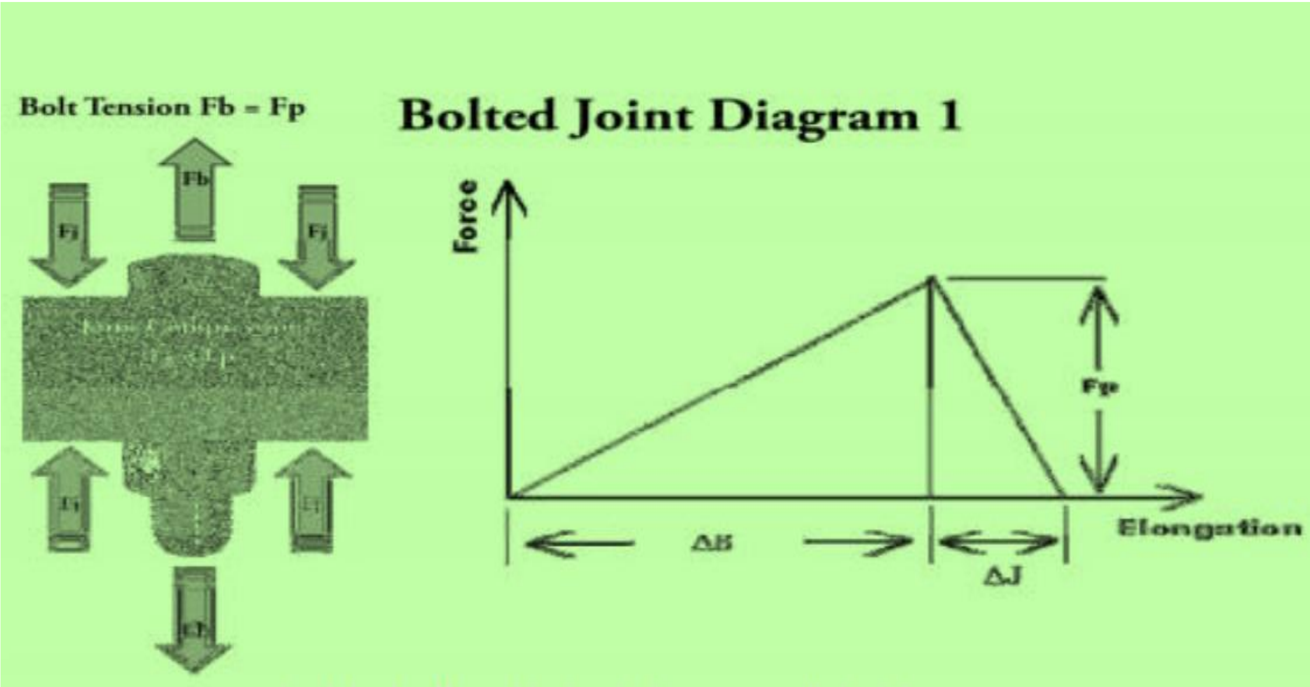


Figure 16 bolted joint diagram due to the force acting

A tension joint is affected by loads that try to pull the join forces on the joint and those on the bolts are parallel to the axes of the bolts the bolt elongates (ΔB). Due to the internal forces resisting the elongation, a tension force or preload is produced (Fp). The tension force on the bolt is equal to the compression force on the joint (which is equivalent to the preload this will change with the application of an external load) Notice the constant slope or straight-line relationship between the force and elongation.

- ΔJ represents the amount that the joint has compressed. As is illustrated, ΔJ is smaller than ΔB. These values represent the stiffness of each component often a bolt will only be about 1/3 to 1/5 as stiff as the joint that it is being used in
- to define the bolt preload, we use different formulas such as the given one, which connect the torque applied and bolt preload:

$$P = T \,/\, K \times D$$

With:
P: Bolt preload.
T: Torque applied.
K: Nut factor or tightening factor.
D: Major diameter of the bolt.

2.9. When an external tensile force (F) has been applied:

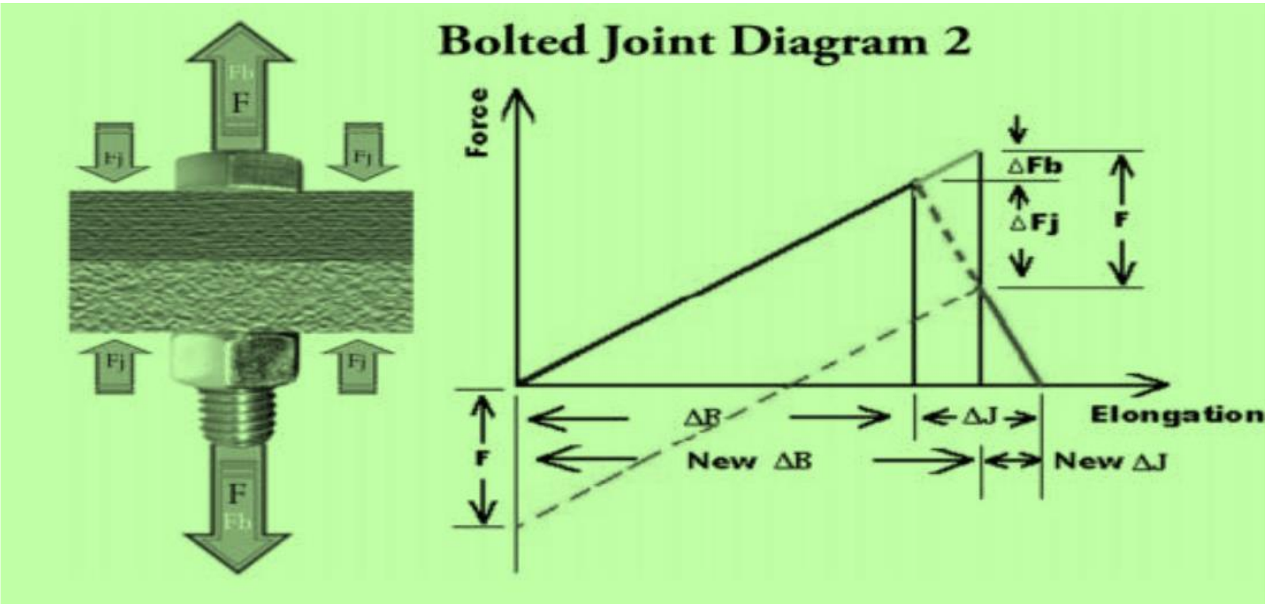


Figure 17 the effect of force addition at external load on bolted joint

- The addition of this force reduced some of the clamping force on the joint (ΔFj) and applied an additional force on the bolt (ΔFb)[24]
- The bolt will further elongate (new ΔB), and the joint compression will be reduced (new ΔJ). The increase in length is equal to the increase in thickness of the joint.

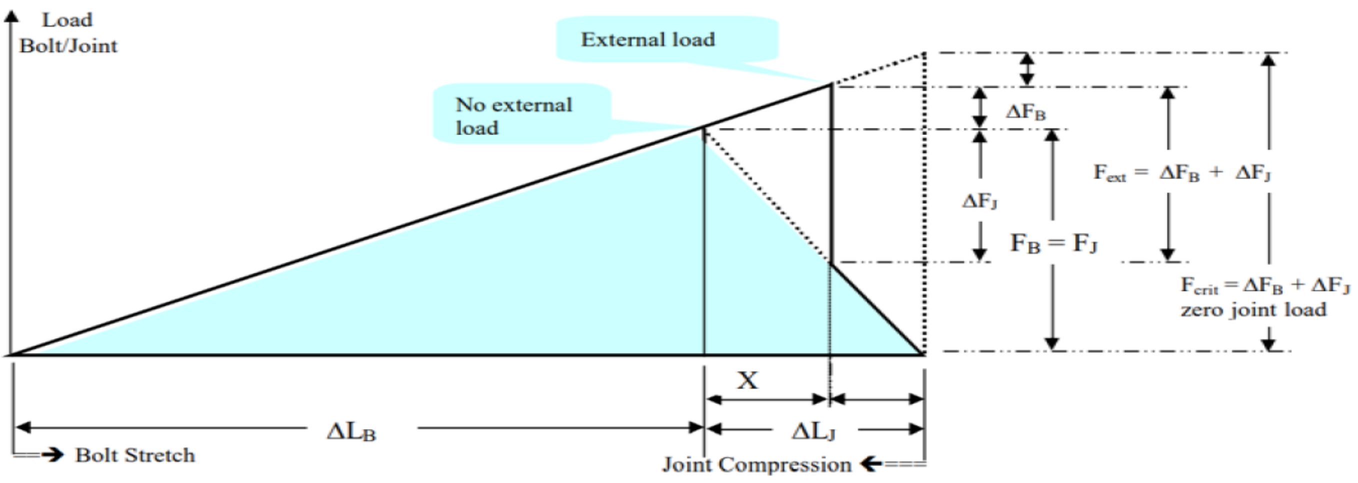


Figure 18 the difference with and without external load on the joint diagram

2.10. What happens If the applied load (F) is allowed to increase

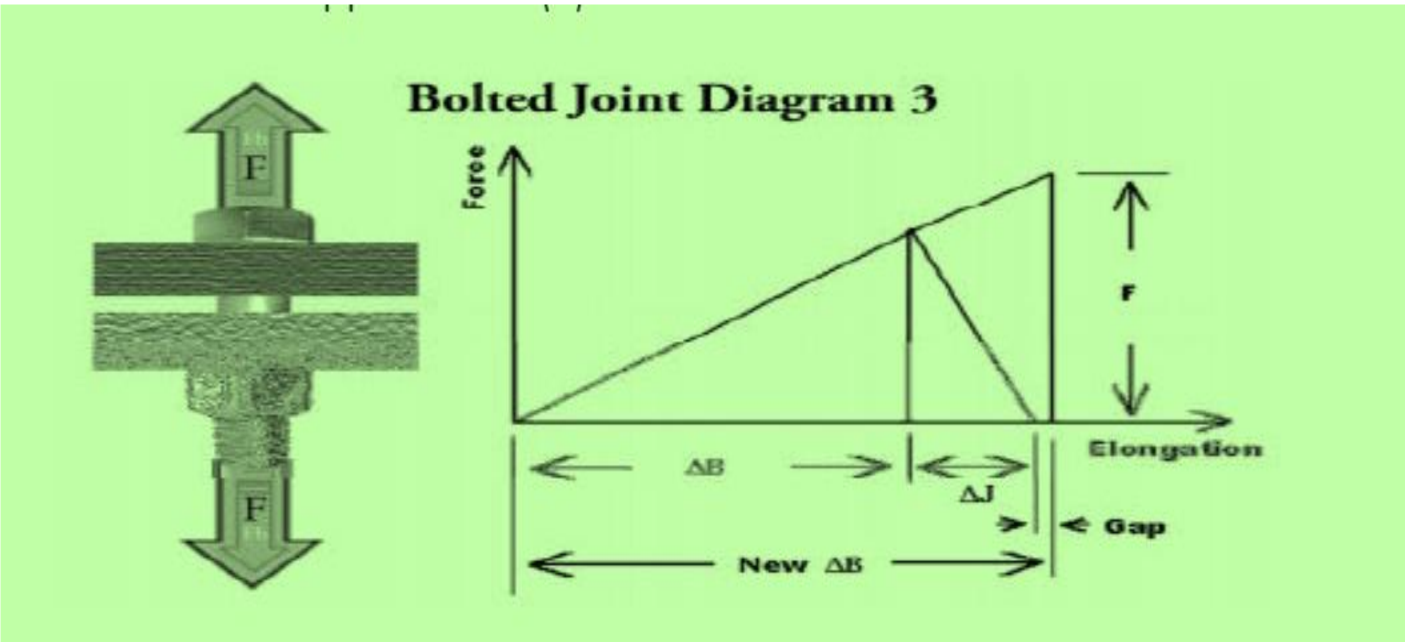


Figure 19 The effect of increasing force on bolted joint

The clamping force acting on the joint will continue to decrease (ΔJ = 0) which will result in a gap between the plates and the bolt. In this case, the bolt is almost always subjected to non-linear loadings from bending and shear forces. This quickly leads to bolt failure.

3. Materials and Methods

3.1. Laboratory measurement Device

In the laboratory, we can observe this device that was designed to perform many measurements on bolts and washers. This design was made for this study to measure these various mechanical fasteners while maintaining the original design of its built-in sensors and strain gauges.

Figure 20 Laboratory Measurement Device (MATE MIK, SKF laboratory Gödöllő).

This custom design became the foundation of our research and allowed for the thorough evaluation of several mechanical fasteners. Importantly, this clever adaptation has been skillfully carried out without affecting the device's basic design.

3.2. Measurement Device components and function

The components of the measurement instrument are made of S355 steel. S355 steel is a low carbon, medium tensile steel with manganese that is readily welded, highly impact resistant, and works well in cold temperatures. The natural or normalized state of this substance is routinely supplied.

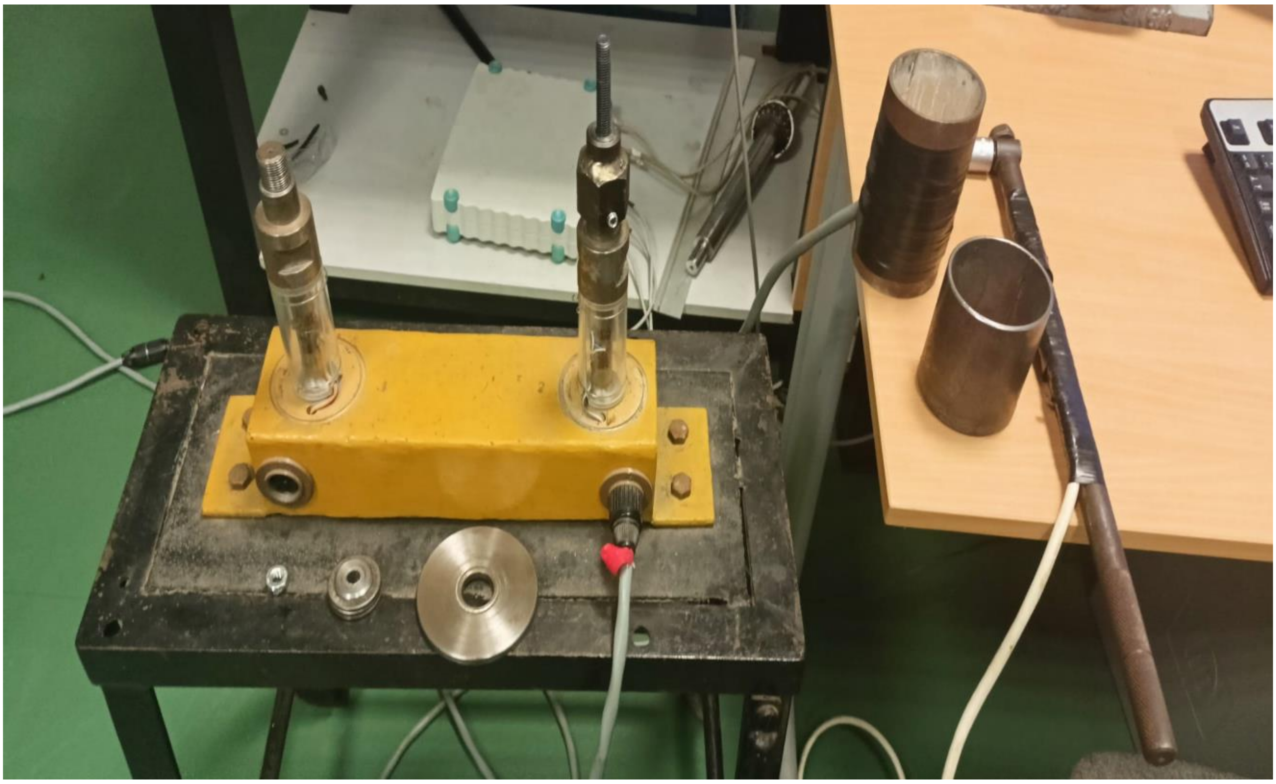


Figure 21 Measurement Device disassembled components

The measurement device consists of:

- Torque wrench with adaptive bolt tightening sleeve
- Cylindrical disk
- Washer seat
- Upper outer frame cylinder
- lower outer frame cylinder
- Measuring screw
- Strain gauge
- Support with a large hexagonal nut
- The desired testing bolt

3.2.1. The Torque wrench with adaptive bolt tightening sleeve

Figure 22 Torque wrench and a bolt-tightening sleeve of the measurement device

The functions of a torque wrench and a bolt-tightening sleeve are integrated into this unique instrument.

Applying a certain amount of torque to a bolt or fastener is the main purpose of a torque wrench. This is essential for the bolted joint to have the desired preload (tension). Engineering standards or guidelines frequently specify the torque value to ensure uniformity and the right clamping force.

The adaptive bolt tightening sleeve is made to fit around the fastener or bolt, making it easier to apply torque uniformly while guarding against overtightening.

The torque wrench with an adaptive bolt tightening sleeve combines precision torque application with a guiding mechanism that guards against excessive torque and guarantees even torque distribution.

3.2.2. Cylindrical disk

The function of the cylindrical disk that covers the upper cylinder and is the base on which the washer seat is fixed and the desirable test bolt for the experiment

Figure 23 Cylindrical disk part of the measurement device.

3.2.3. Washer seat

Washer seat for nut used for bolt nut size such as M10 bolts.

Figure 24 Washer seat for M10 part of the measurement device

3.2.4. Lower frame cylinder

The lower frame cylinder in the measurement device is connected by a wire to an electronic data logger device to transfer signals into real measurement values

Figure 25 The lower frame cylinder in the measurement device

3.2.5. upper frame cylinder

Is the upper cylinder frame out above the lower cylinder as the outer covering.

Figure 26 upper outer frame cylinder of the measurement device

3.2.6. Measuring screw with the strain gauge sensor

Strain gauge sensors convert applied force into a measurable electrical signal. A strain gauge measures the force as a change in resistance, which is subsequently used to gather the voltage.

Real strain gauge assembly is attached to the measurement screw and measures electrical resistance, which varies with tension. Applying stress to a substance results in strain. A material's cross-sectional area is divided by force. Focus stress by using beam components equipped with strain gauges

Figure 27 Measuring screw with the strain gauge sensor inside part of the measurement device

3.2.7. Connecting sleeve

In this device, the connecting sleeve plays a crucial role in effectively and securely combining two or more components, the desirable test bolt fits in for testing process this sleeve, which is frequently constructed of sturdy materials like metal or composite, is essential for preserving the integrity and dependability of the fastener assembly. How the connecting sleeve works is described here

It serves as a crucial link that encourages component alignment, stability, load distribution, and increased durability.

The test bolt is fit into the connecting sleeve inside the device for it ensures that the components are perfectly positioned.

Figure 28 Connecting sleeve part of the measurement device

Figure 29connecting sleeve with the test bolt fit into it for experiment

3.2.8. Bearings

The bearings used in the experiments of testing bolts for several measurements of factors needed

Figure 30 Bearings used in the laboratory measurement device

The laboratory's real structural device setup after connecting all of the parts and preparing for testing measures.

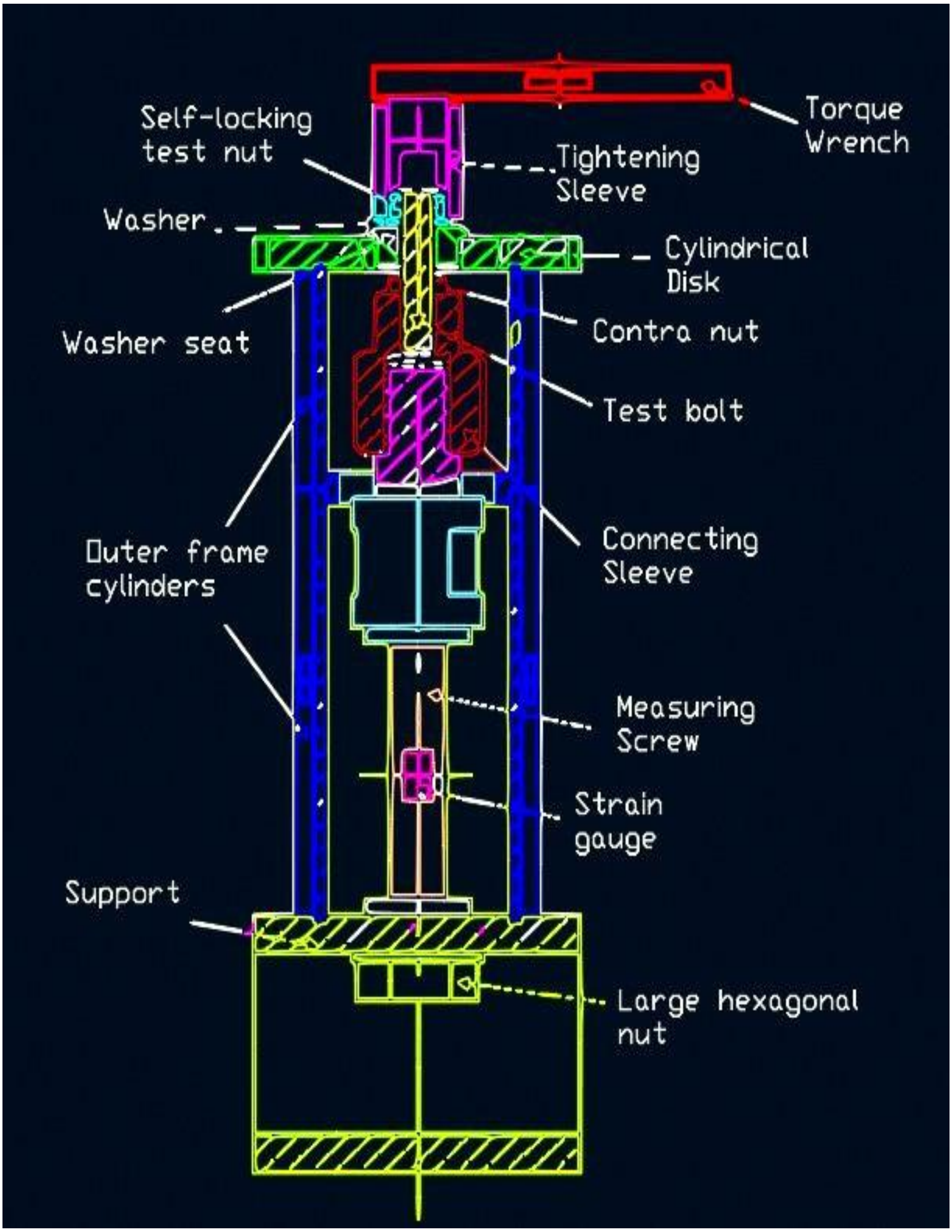


Figure 31 Schematic diagram of the measuring device.

3.2.9. Electronic data processing device

An electronic device that continually monitors and records the input data, and enables the measurement, documentation, analysis, and validation of conditions, is the data logger measuring instrument utilized in this study.

Even the smallest alterations in real-time data are completely documented because of this advanced tool's unmatched accuracy in capturing. It enables researchers to discover trends, patterns, and anomalies that would elude conventional observation by seamlessly gathering data throughout time measuring

Catman is the software that was utilized in this study to collect, visualize, and analyze the measurement data.

Figure 32 Electronic signals spider 8 data device device.

3.2.10. Data Monitor

The data monitor is connected to the electronic data analysis device which shows data using Catman software evaluating the values of torque and elongation values in the experiments in real-time monitoring, analysis, and interpretation of data in laboratory measurements, the data monitor is vital for researchers. It eventually advances scientific understanding and discovery by providing scientists with rapid insights, enabling quick modifications, and contributing to the quality and accuracy of experimental data.

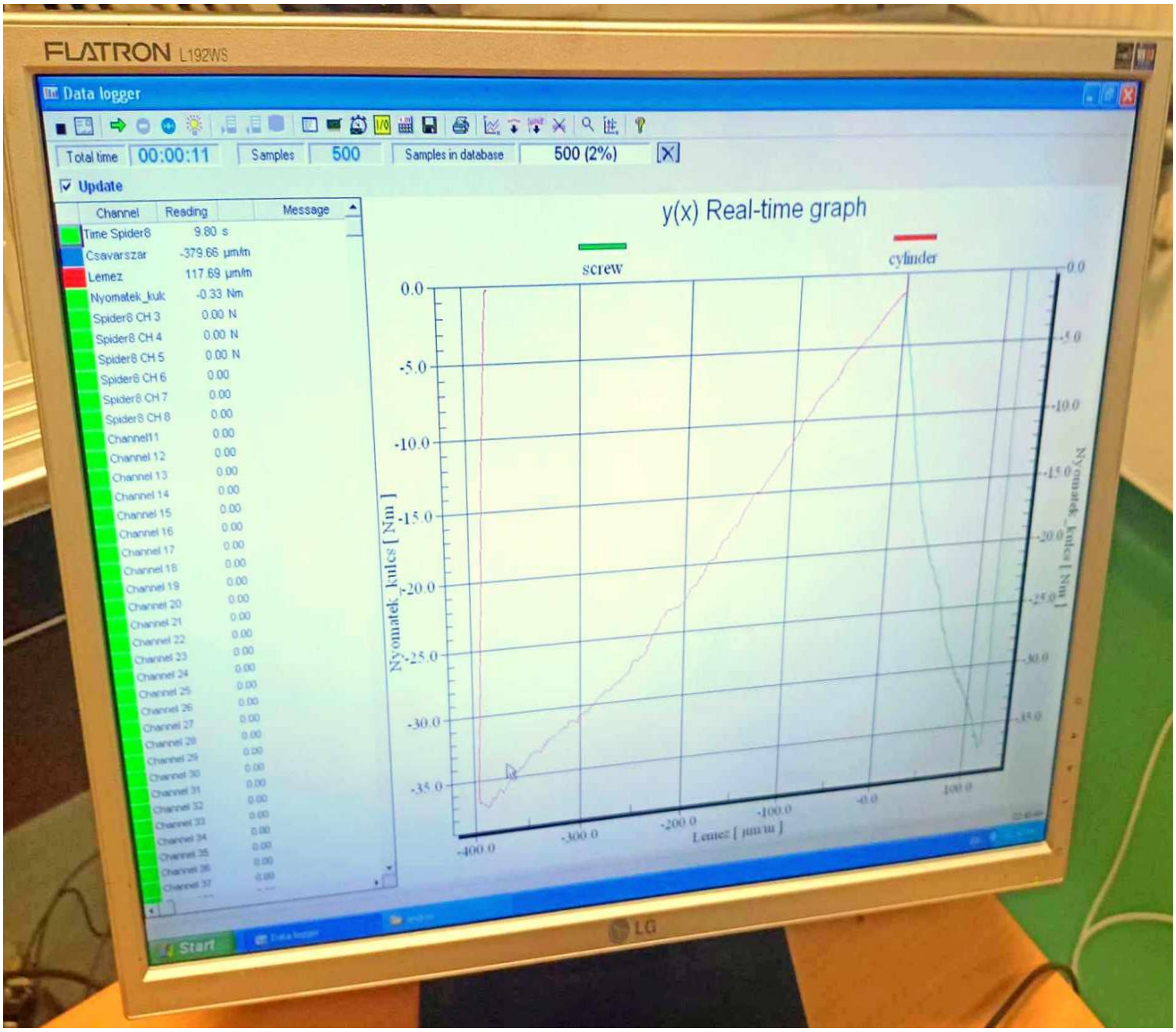


Figure 33 Data monitor connected to data analysis device which shows data using Catman software

3.1. Materials

The following materials were used in the experiment for testing the friction of bolts and washers and even the contra nut used in the testing process.

3.3.1. M10 stainless-steel bolts with different yield strength

M10 stainless steel bolts are commonly used in a variety of industries. These bolts have several grades, each with a unique yield strength. A critical mechanical parameter called yield strength determines a bolt's ability to sustain applied loads without permanently deforming. The standard stainless steel bolt grades for M10 screws are 5.6, 5.8, 8.8, and 10.9, each with unique benefits and uses.

		Bolt class						
Symbol	**Description**	**4.6**	**4.8**	**5.6**	**5.8**	**6.8**	**8.8**	**10.9**
f_{yb} (MPa)	Yield strength	240	320	300	400	480	640	900
f_{ub} (MPa)	Ultimate tensile strength	400	400	500	500	600	800	1000

Table 1 M10 stainless-steel bolt class types with their yield strength and ultimate strength [2]

1. M10 bolts made of steel and having a yield strength of 5.6 are ideal for situations where a moderate level of strength is required while keeping costs in check. These bolts are commonly used in critical assemblies where strict safety requirements are not necessary. They work well for fastening components in mechanical connections that don't meet demands.

2. Consider using M10 stainless steel bolts with a yield strength of 5.8. With a minimum yield strength of 580 MPa, these bolts offer reliability. Are suitable for applications where moderate load-bearing capacities are needed. Industries like automotive and construction often rely on them to secure components subjected to stress and dynamic forces.

3. M10 stainless steel bolts with an 8.8-grade yield strength should be considered for applications requiring load-bearing capacities and tensile strength. These bolts exhibit a yield strength of 800 MPa, indicating higher strength levels than lower-grade options. They find use in structural connections across industries such as construction, bridges, and heavy machinery due, to their paramount safety and durability.

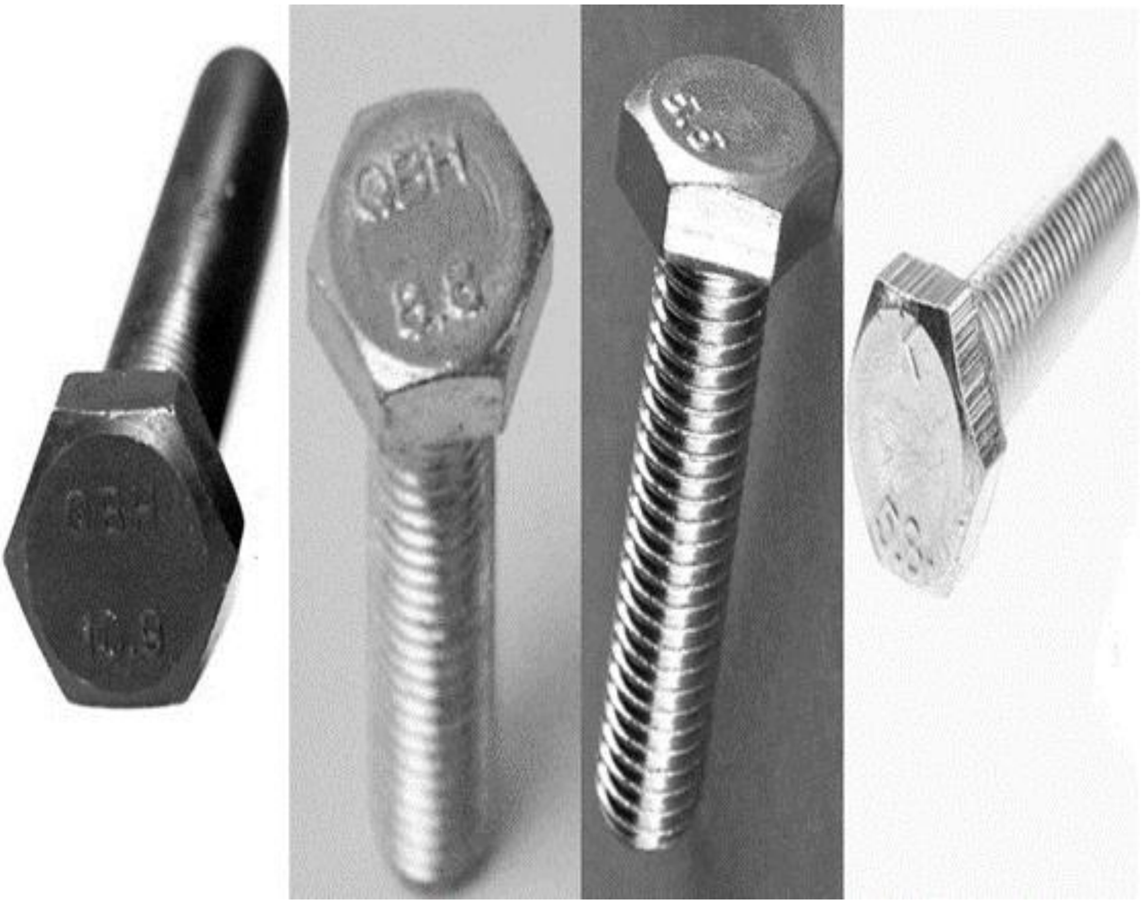


Figure 34 M10 stainless steel bolts with different yield strength

4. M10 bolts, with a 10.9 grade have a minimum yield strength of 900 MPa. These bolts are specifically designed for situations that demand strength in environments with high levels of stress and heavy loads. They are commonly used in scenarios where safety and precision are factors to consider.

3.3.2. Key Properties and Characteristics of Used Bolts

The properties and characteristics of the bolts with different yield strengths and the details of their chemical properties are shown in this table

Yield Strength Grade	Chemical Composition (% by weight)	Key Properties and Characteristics
5.6	Carbon (C): ≤ 0.20%	Cost-effective, moderate strength, suitable for Non-critical applications.
	Manganese (Mn): 0.70 -1.00%	
	Phosphorus (P): ≤ 0.045%	
	Sulphur (S): ≤ 0.050%	
5.8	Carbon (C): ≤ 0.25%	Increased strength and reliability, commonly Used in moderate load-bearing applications.
	Manganese (Mn): 0.80 -1.20%	
	Phosphorus (P): ≤ 0.045%	
	Sulphur (S): ≤ 0.050%	
8.8	Carbon (C): ≤ 0.30%	High tensile strength and durability, suitable for Critical structural connections.
	Manganese (Mn): 0.80 -1.20%	
	Phosphorus (P): ≤ 0.045%	
	Sulphur (S): ≤ 0.040%	
	Chromium (Cr): 0.30 - 0.50%	
10.9	Nickel (Ni): ≤ 0.40%	Exceptional strength and reliability, used in High-stress environments.
	Carbon (C): ≤ 0.40%	
	Manganese (Mn): 0.30 -0.60%	
	Phosphorus (P): ≤ 0.035%	
	Sulphur (S): ≤ 0.040%	
	Chromium (Cr): 0.90 - 1.20%	

Table 2 Key Properties and Characteristics of Bolts with Different Yield Strength [25]

3.3.3. M10 Flat washer

The M10 flat washer is a simple yet essential component used in various mechanical and construction applications. Its primary function is to distribute loads and use for reducing friction and providing a smooth, even surface under a bolt head or nut.

Each one has its geometries and dimensions.

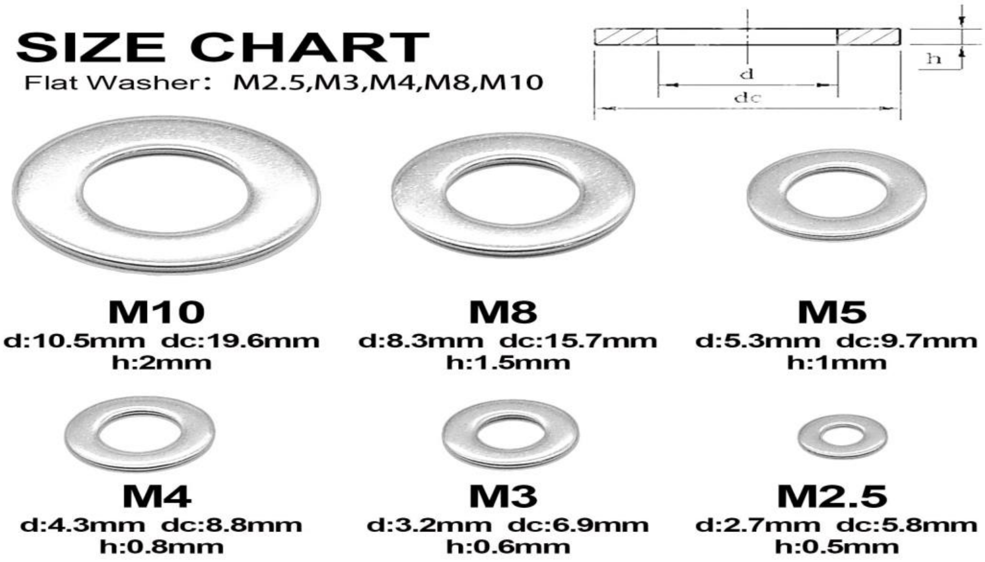
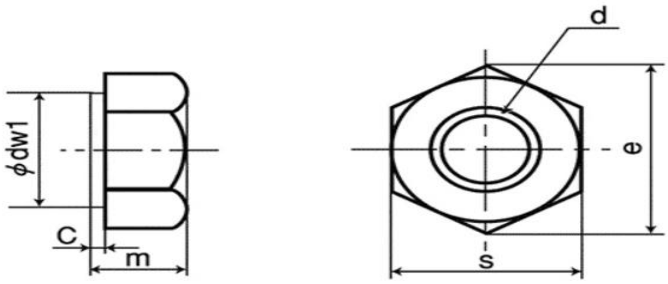


Figure 35 Flat washers size chart and dimensions

Figure 36 M10 flat washer in the measuring device used during the experiments

3.3.4. M10 metric nuts

Nuts were utilized during testing to prevent the bolt from sliding or mechanically loosening. Metric nuts are adaptable components that are necessary in a wide range of applications and industries to guarantee the safe and secure assembly of mechanical systems. The figure shows each geometries and dimensions.



Unit: mm

Screw Nominal	m		s		e	dw1	c
	Reference Dimensions	Tolerance	Reference Dimensions	Tolerance	Approx.	Minimum	Approx.
M8	6.5	0 −0.36	13	0 −0.25	15	11.7	0.4
M10	8		17		19.6	15.8	0.4
M12	10		19	0 −0.35	21.9	17.6	0.6
M14	11	0 −0.43	22		25.4	20.4	0.6
M16	13		24		27.7	22.3	0.6
M18	15		27		31.2	25.6	0.6
M20	16		30		34.6	28.5	0.6

Table 3 Locking nuts size table and its corresponding geometries [26]

Figure 37 M10 Locking nuts in the measuring device used during the experiments

3.2. Methodology

The purpose of measurement is to get reliable data for measurements of coefficients of friction of several bolts with different yield strengths in the first experiments and to measure coefficients of friction of several washers for which to answer research questions assess theories of change and emphasize objective measurements for numerical analysis of the collected data.

3.4.1. Applied method for testing bolts coefficient of friction

Setting up the measurement device Strain gauges are equally pasted on the spherical surface in the center of the measuring sleeve to set up the measurement equipment. The measuring sleeve's Centre cross-sectional region experiences homogeneous stress distribution, and axial strain measurements made using strain gauges can be used to calculate deformation.

The measurement device is connected to the electronic data processing device Spider 8 and data monitor and with Cat Man software for testing converted signals and software for beginning the measurement process

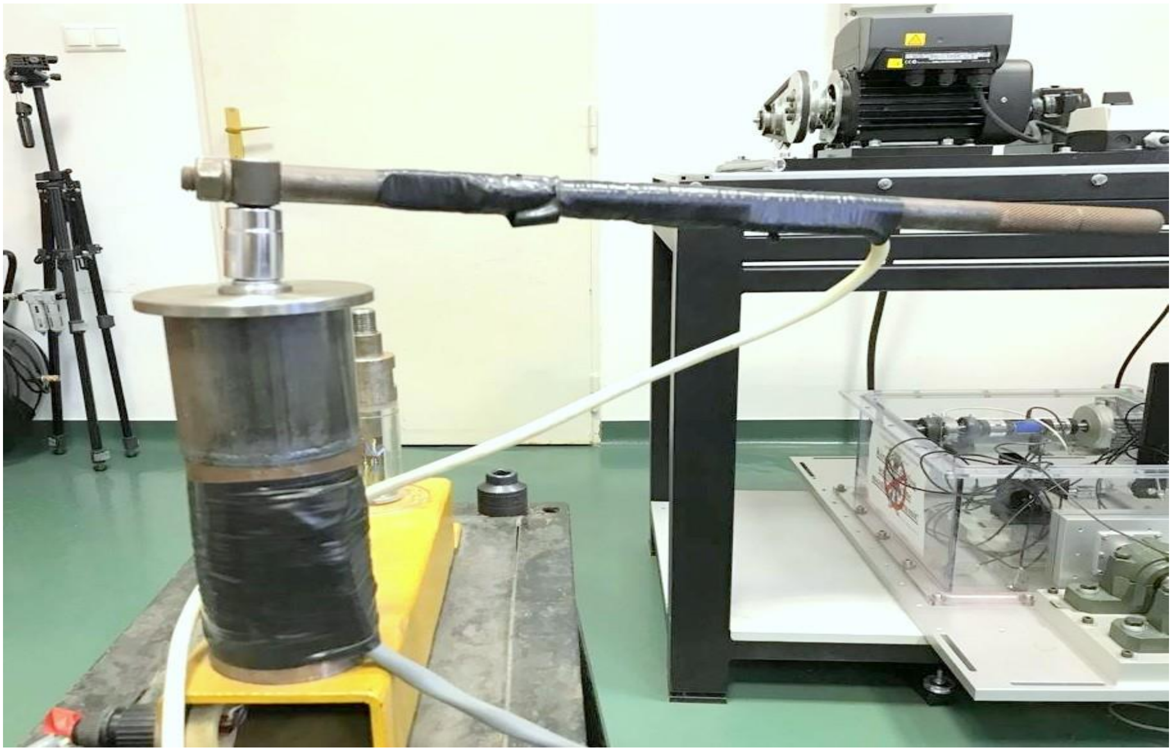


Figure 38 Testing the measurement device before the beginning of testing in experiments

Preparing the M10 bolts fully thread stainless-steel hex bolts for experimental measurements as we have 20 bolts with different yield strengths and cutting the bolt's head using the cutting machine to be able to fit into the measurement device perfectly with its nut

Figure 39 Electric cutting machine for cutting bolts-head before the experiments

After cutting all bolts-head the collected bolts of the same yield strength are gathered together and divided into four groups Each group consists of five bolts of the same yield strength and is numbered for the testing process

The first group A has a yield strength of 5.6 the second group B has a yield strength of 5.8, the third group C has a yield strength of 8.8 and the fourth group D has a yield strength of 10.9

Each group consists of five M10 bolts of the same yield strength and each bolt has its nut for testing and is numbered for the testing process in the experiment as follows:

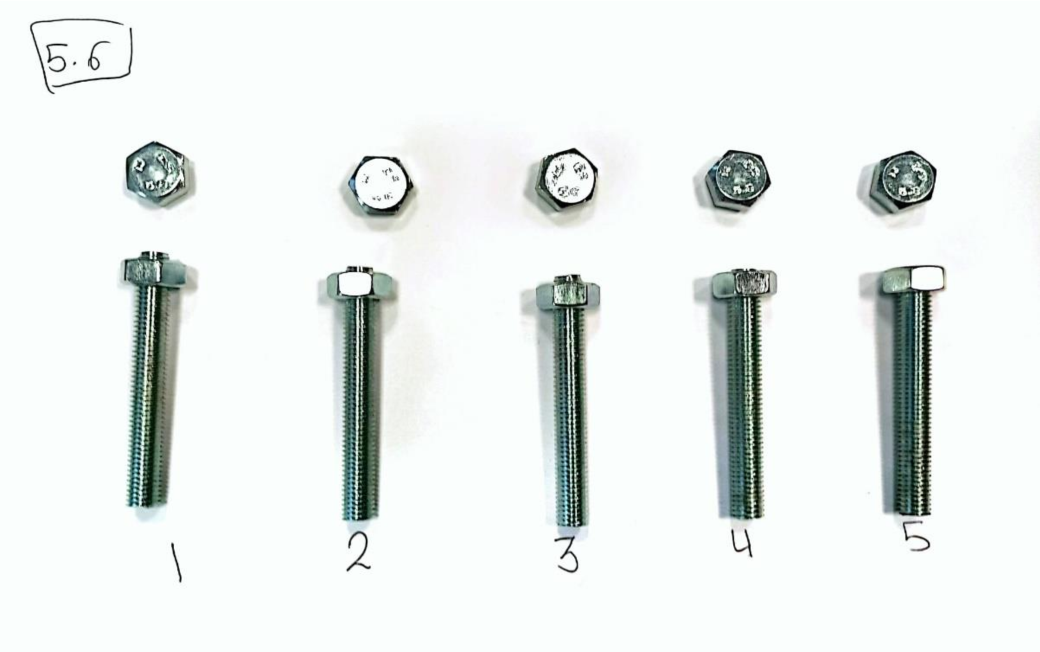


Figure 40 Group A of M10 bolts have a 5.6 yield strength with locking nuts

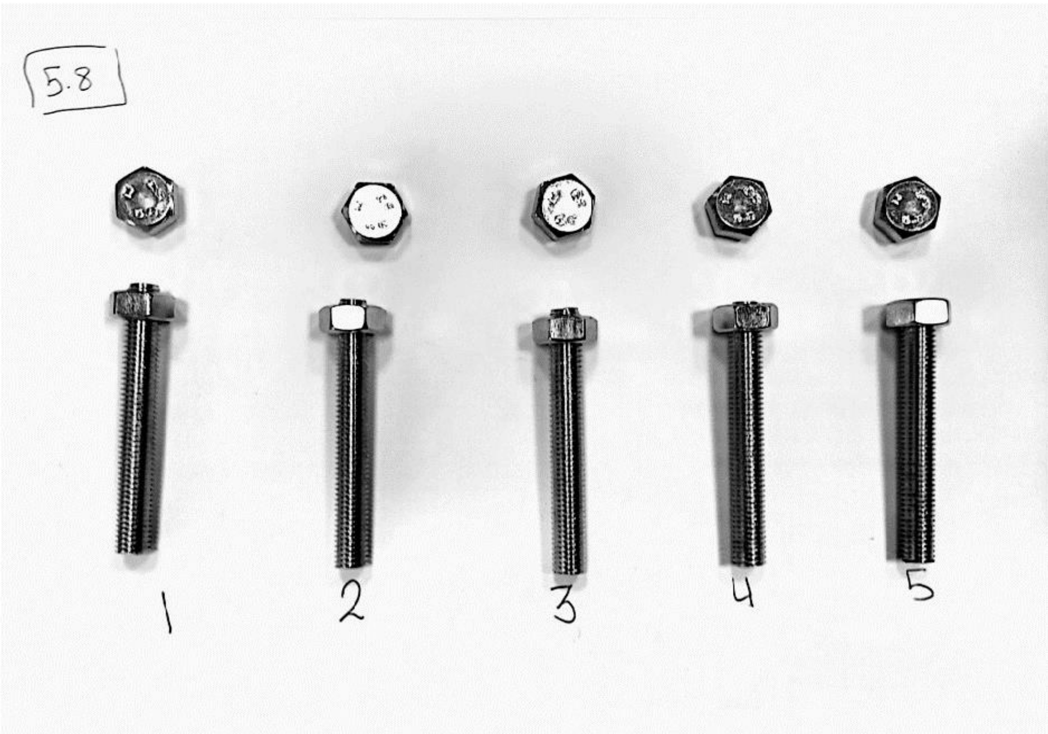


Figure 41 Group B of M10 bolts have a 5.8 yield strength with locking nuts

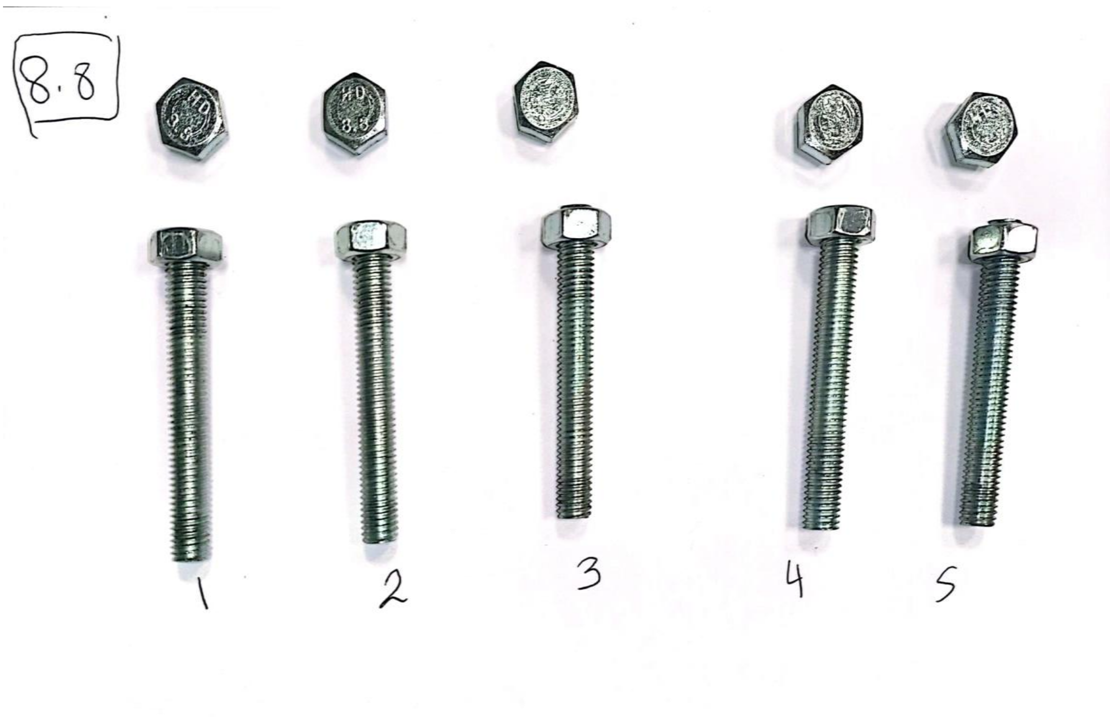


Figure 42 Group C of M10 bolts have a 8.8 yield strength with locking nuts

Figure 43 Group D of M10 bolts have a 10.9 yield strength with locking nuts

After the device is set up and the testing bolts are ready, for testing the thread frictions, apply the bearings in the testing device which have a negligible torque and friction value to be able to measure and obtain bolt thread coefficients of friction threw other parameters and calculated values using the proper equations.

Tightening torque is manually applied with constant speed until the nut is fully locked; the torque is realized by untightening the nut.

For each single bolt in each group of yield strength M10 bolt the test process is repeated five times with tightening and locking each nut on the appropriate bolt.

Detecting the elongation happening for each bolt due to axial force in each bolt by the applied certain torque with the help of the software data on the monitor.

Figure 44 testing the coefficient of friction of M10 Bolts device setting up with applied bearing

The deformation of the measuring screw and the cylinder as a function of the applied torque during the operation is shown in a diagram of the test results, the screw is finally under tension, and the cylinder is under compression.
The collected parameters during the test are extracted in an Excel file for each test measurement of the tightening torque (Mt) in [Nm] and the deformation in both the screw and the cylinder ε in [μm/m].

Test results can be seen in the Catman software in a diagram where we have the deformation of the measurement screw and the cylinder in the function of the applied torque during the process. Hence, we finally get tension on the screw and compression on the cylinder.

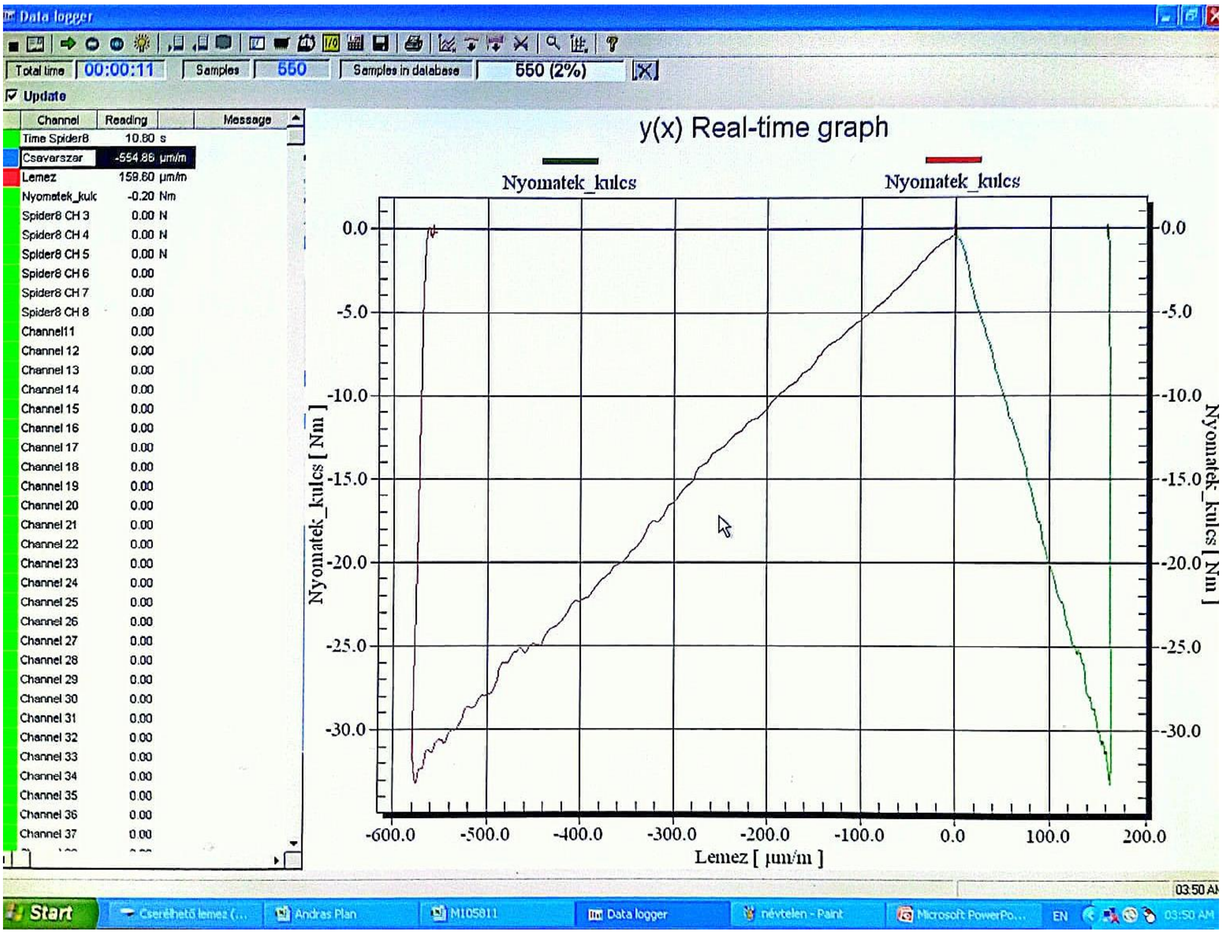


Figure 45 Catman software real-time graph for the measured parameters

3.4.2. Applied method for testing washer coefficient of friction

Testing the M10 washer coefficient of friction using the same measurement tool to evaluate the washer coefficient of friction starts with putting the measurement equipment in place to set up the measurement apparatus, strain gauges are evenly pasted on the spherical surface in the middle of the measuring sleeve.

The measurement device is linked to the data monitor, Spider 8 electronic data processing device, software for testing transformed signals, and Cat Man to start the experiment.

Getting the M10 x 1.5 bolts with various yield strengths ready for experimental measurements and cutting the bolt's head with the cutting machine to fit exactly into the measurement instrument with its nut.

After removing every bolt's head, the bolts with the removal of every bolt's head, the bolts that have the same yield strength are gathered and separated into four groups. For the testing procedure, each group consists of the testing bolts with the same yield strength and each bolt has its own washer for testing and all are numbered.

The yield strength of the first group A is 5.6; the yield strength of the second group B is 5.8; the yield strength of the third group C is 8.8; and group D is 10.9.

Figure 46 Group A of M10 bolts have a 5.6 yield strength with washers and locking nuts

Figure 47 Group B of M10 bolts have a 5.8 yield strength with washers and locking nuts

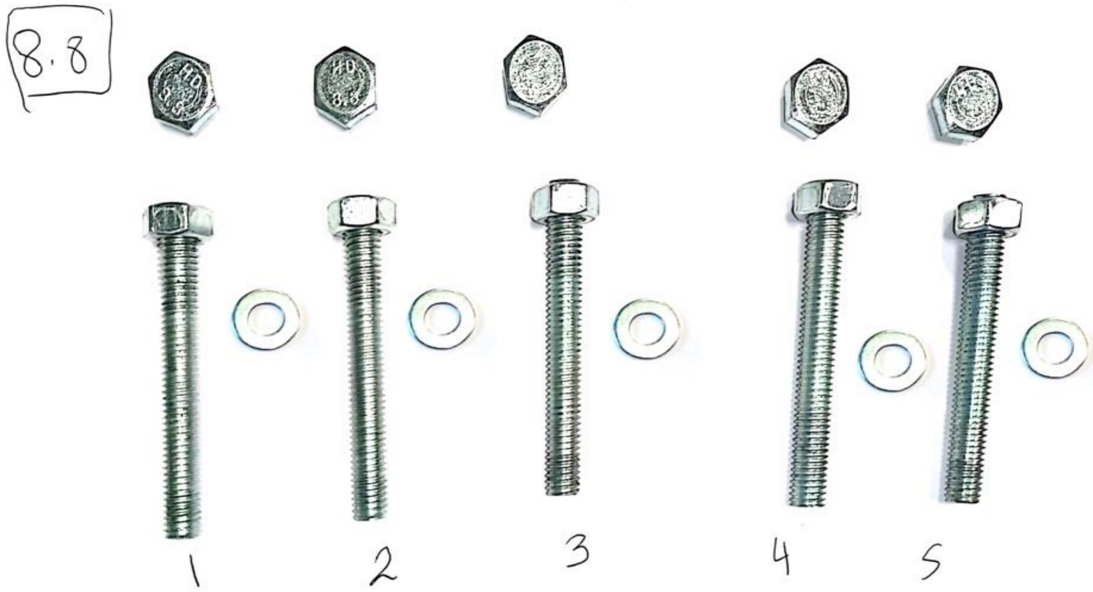


Figure 48 Group C of M10 bolts have an 8.8 yield strength with washers and locking nuts

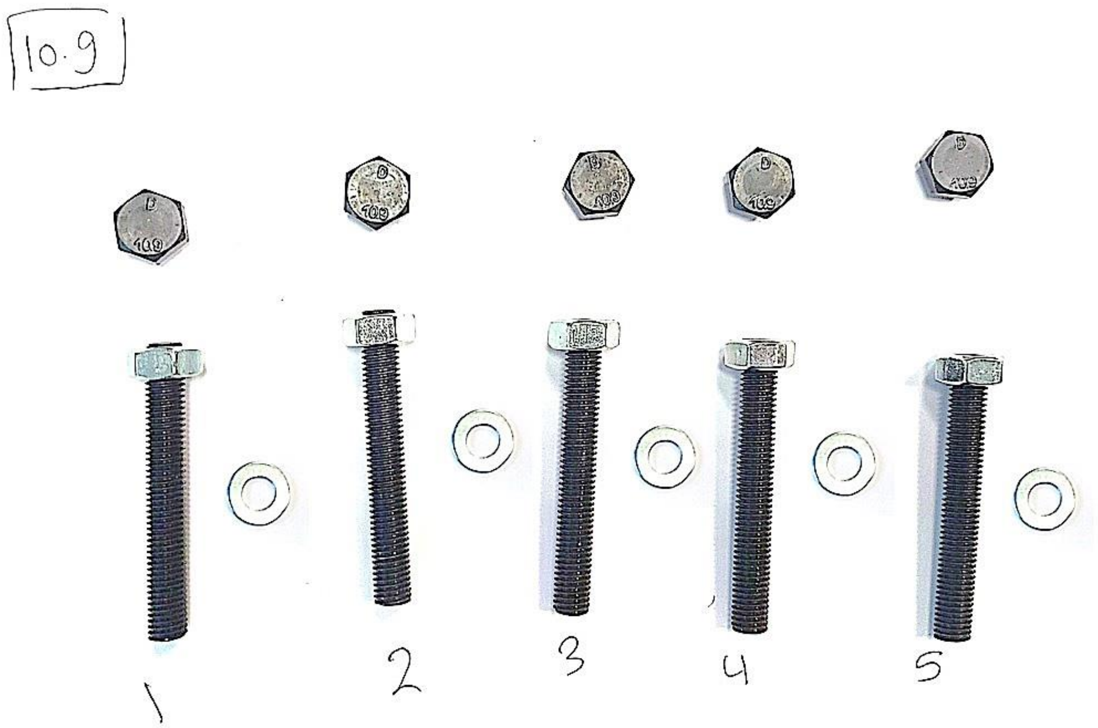


Figure 49 Group D of M10 bolts have a 10.9 yield strength with washers and locking nuts

After the device is set up and the testing bolts are ready, for testing the washer coefficient of friction, apply an M10 washer for each bolt in the testing device to be able to measure and obtain the washer coefficients of friction threw other parameters and calculate values using the proper equations.

Tightening torque is manually applied with constant speed until the nut with the contacted washer is fully locked; the torque is realized by untightening the nut.

For each washer with each bolt, the test process is repeated five times, tightening and locking each nut on the appropriate bolt.

Using the software data displayed on the monitor to identify the elongation occurring for each bolt as a result of the axial force generated by the imposed specific torque.

A graphic of the test results in the Catman program illustrates the deformation of the measuring screw and the cylinder as a function of the applied torque during operation. As a result, the cylinder is now under compression and the screw is finally under tension.

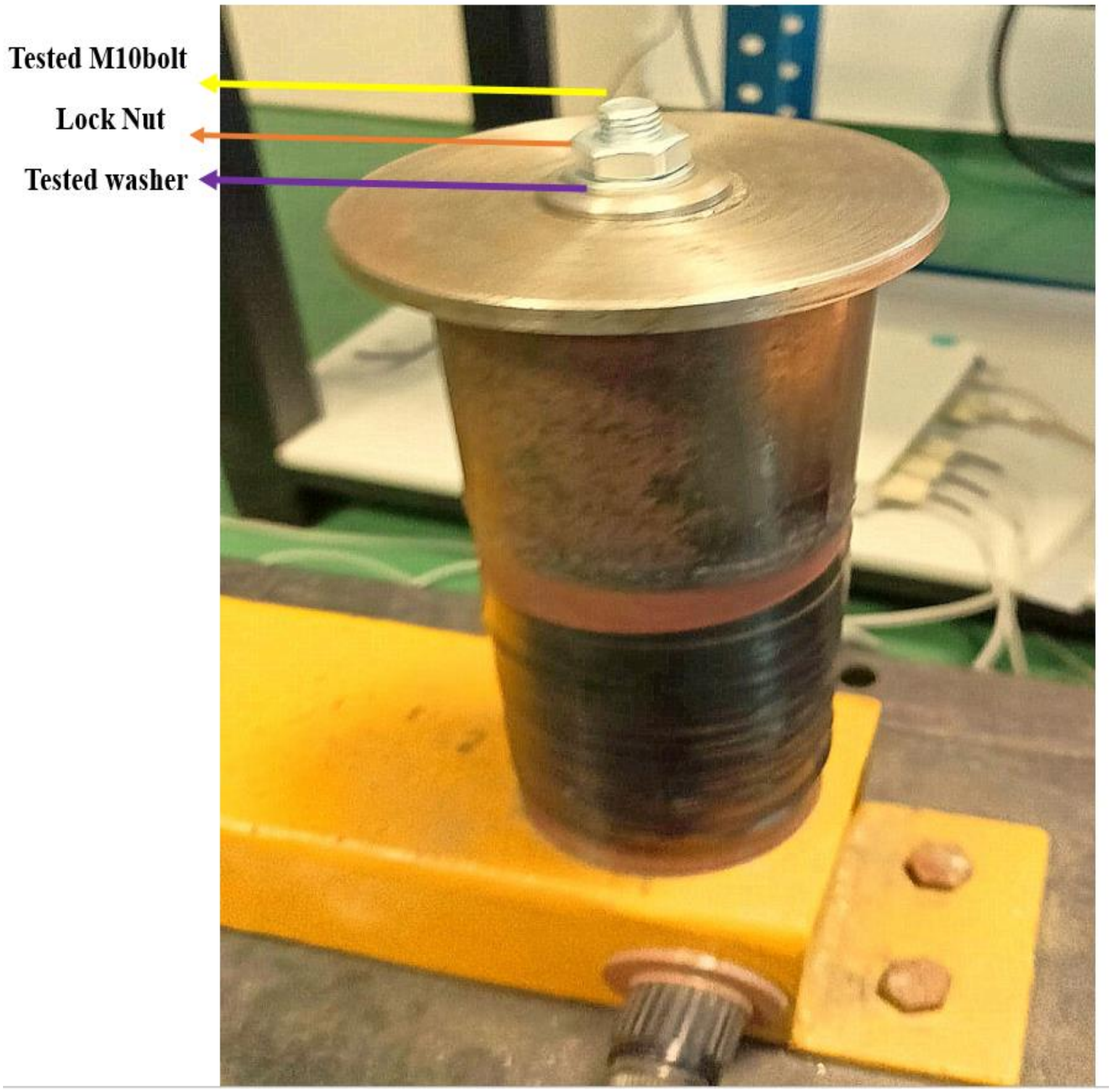


Figure 50 testing the coefficient of friction of M10 washers device setting up with applied washers

Integrate the prepared bolts and appropriate washers into the measuring device. Make sure the bolts are firmly fastened inside the device and are well-fitted.

Verify that the measurement tool is set up to handle the intended testing requirements, including the measurements to perform and the probable range of results.

The measured parameters during the test are extracted in an Excel file for each test measurement of the tightening torque (Mt) in [Nm] and the elongation in both the screw and the cylinder ε in [μm/m].

4. Results and Discussion

Regarding a comprehensive analysis of the two experimental data for testing bolts' coefficient of friction and washer coefficient of friction and considering the collected parameters in the experiment, the used equations, the final values, and their characteristics.

4.1. Extraction of the values of bolts' coefficient of friction

In the experiment where bolts with different yield strengths are subjected to an axial load using strain gauges, the behavior of the bolts will vary based on their respective material properties and yield strengths.

The M10 bolts are stretched throughout the tightening process, resulting in an axial preload equal to the tension of the measurement screw and the torque exerted can be recognized directly by the measurement device software. Thus, torque and its corresponding deformation value can be extracted for each measurement.

Then the pretension axial force (F_a) acting on the screw is calculated as the following:

- Since the stress is ($\sigma = \frac{F}{A}$) Where F is the force exerted and A is the cross-sectional area.

  Also, ($\sigma = E \cdot \varepsilon$) where E is Young's modulus, ε is the elongation, ($\varepsilon = \frac{\triangle L}{L}$)
- The collected parameters which are the tightening torque (Mt) in [Nm] and the deformation in both the screw and the cylinder ε in [μm/m], The measured elongation ε, which is multiplied by 10^{-6} because the achieved deformation was in [μm/m].
- The cross-sectional area A which the axial force acting on the stain gauge calculated A=$226.98 mm^2$.
- The Young's modulus of the used stainless bolts in the experiment (E)=210000[MPa].

  Thus the axial force exerts force (Fa) is calculated using the equation:

$$F_a = A \cdot E \cdot \varepsilon$$

Then bolt thread coefficient of friction μt can be calculated as follows:

- The applied tightening torque Mt exerts on the bearing and the bolt.

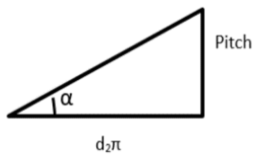
  Mt = Mb+ MR, where MR: is the bearing tightening torque is almost negligible and its friction is negligible Thus MR =0, So that the applied tightening torque Mt exerts is equal to torque on bolts so that Mt =Mb

- Mb: The tightening torque on bolts can be evaluated by this equation:

$$Mb = Fa * \frac{d2}{2} * \tan(\alpha + \rho)$$

Where (d2) is the pitch diameter of an M10 bolt is approximately 9.026 mm. from M10 metric table, and (α) is the friction angle of the bolt can be evaluated from this equation:

Tanα = $\frac{pitch}{d2\pi}$



, thus α =3.02, M10 thread pitch =1.5 mm

- After evaluating all parameters the value of (ρ) friction angle of the metal the bolt thread can be calculated

Thus the Coefficient of friction value μt using the equation:

$$\mu t = \tan \rho$$

A certain selected torque value for M10 bolts is 15[Nm] is identified to analyze the relationship/performance of the pretension force with the coefficient of frictions in the function of the screwing times on the test bolt; hence the measurement cannot be an absolute value due to possible variations happening during the test. Thus, we allow a tolerance of ± 3 % of the chosen torque value.

As shown in the tables of results each bolt group has the same yield strength Thus, we have the number of the used bolts represented in rows, and the columns express the number of tests as we progress in the measurements. The measured axial force and the calculated coefficient of friction are presented for each bolt of its corresponding test.

Bolts Test	BOLT 1		BOLT 2		BOLT 3		BOLT 4		BOLT5	
M10 5.6	Fa	μt	Fa	μt	Fa	μt	Fa	μt	Fa	μt
Test 1	13106.5	0.19819	13773.74	0.18618	12391.6	0.21247	12629.9	0.20753	14774.6	0.17017
Test 2	13583.1	0.18949	14059.7	0.18137	13154.2	0.19729	13297.14	0.19463	15894.61	0.15462
Test 3	13821.4	0.18536	15479.97	0.16012	13743	0.1867	13726.08	0.187	16681	0.14494
Test 4	14169.3	0.17958	16070.95	0.15237	14250.3	0.17828	14107.36	0.18059	17538.88	0.13536
Test 5	15279.8	0.16288	16442.7	0.14778	15060.6	0.16598	15489.5	0.15999	18349.1	0.12712

Table 4 GroupA results of M10 (5.6 yield strength) bolts axial force and coefficient of friction values

Bolts Test	BOLT 1		BOLT 2		BOLT 3		BOLT 4		BOLT5	
M10 5.8	Fa	μt	Fa	μt	Fa	μt	Fa	μt	Fa	μt
Test 1	11915	0.22293	9532	0.29064	9512.94	0.29132	8859.994	0.31619	8588.332	0.32763
Test 2	13835.2	0.18513	9817.96	0.28081	9903.75	0.27797	9408.084	0.29508	9546.298	0.29014
Test 3	14113.1	0.1805	10628.18	0.25579	10671.1	0.25456	10504.26	0.25937	10814.05	0.25056
Test 4	14312.3	0.17729	10866.48	0.24912	11462.2	0.23366	11438.4	0.23425	11724.36	0.22735
Test 5	18414.9	0.12649	12320.11	0.21399	13487.8	0.19118	12153.3	0.2176	12329.64	0.21378

Table 5 GroupB results of M10 (5.8 yield strength) bolts axial force and coefficient of friction values

Bolts Test	BOLT 1		BOLT 2		BOLT 3		BOLT 4		BOLT5	
M10 8.8	Fa	µt	Fa	µt	Fa	µt	Fa	µt	Fa	µt
Test 1	8817.1	0.31795	8435.82	0.33437	8960.08	0.31215	8340.5	0.33871	9017.272	0.30988
Test 2	9293.7	0.29929	9770.3	0.28241	9055.4	0.30838	8621.694	0.32619	9474.808	0.29268
Test 3	11581.4	0.23076	10056.26	0.27304	9484.34	0.29234	12210.97	0.21634	10099.15	0.27168
Test 4	12815.8	0.20381	10532.86	0.25853	10008.6	0.21901	13916.72	0.18375	10818.82	0.25043
Test 5	13702.3	0.18741	12143.3	0.2187	10914.1	0.19781	14679.28	0.1716	10990.4	0.24577

Table 6 GroupC results of M10 (8.8 yield strength) bolts axial force and coefficient of friction values

Bolts Test	BOLT 1		BOLT 2		BOLT 3		BOLT 4		BOLT5	
M10 10.9	Fa	µt	Fa	µt	Fa	µt	Fa	µt	Fa	µt
Test 1	8102.2	0.34998	7625.6	0.37459	9913.28	0.27766	9103.06	0.30652	8901.458	0.31451
Test 2	8812.33	0.31815	8550.204	0.3293	13869.1	0.18455	12868.2	0.20277	9511.03	0.29139
Test 3	9674.98	0.28566	9036.336	0.30913	14393.3	0.17601	13678.42	0.18782	10723.5	0.25309
Test 4	10666.3	0.2547	10389.88	0.26275	14669.3	0.17601	14378.55	0.17624	13535.44	0.19033
Test 5	13630.8	0.18865	11142.91	0.24175	16671	0.14394	14869.92	0.16876	14159	0.18147

Table 7 GroupD results of M10 (8.8 yield strength) bolts axial force and coefficient of friction values

4.2. Extraction of the values of the washer coefficient of friction

In the experiment, for testing the coefficient of friction a bolt with a washer is subjected to axial load, torque, and friction, creating a clamping force that holds components together securely. The M10 bolts are elongated throughout the tightening process, the washer helps distribute the load, reduce friction, and ensure even clamping. Proper torque control is essential to achieving the desired preload.

A same certain A certain selected torque value for M10 washers with bolts is 15[Nm] is identified to analyze the relationship of the axial force with the coefficient of frictions in the function of the screwing times on the test bolt; hence the measurement can be perfectly managed by avoiding possible variations happening during the test. Thus, we allow a tolerance of ± 3 % of the chosen torque value.

The washer coefficient of friction (μ_w) can be calculated as follows:

- For using the same measurement device the pretension axial force (Fa) acting on the screw is calculated using the same steps and the same parameters of the tightening torque (Mt) in [Nm] and the measured elongation ε, which is multiplied by 10^{-6} because the achieved deformation was in [µm/m].

The same values of the cross-sectional area A of the stain gauge calculated A=226.98mm^2.
And the Young's modulus of the used bolts in the experiment (E) 210000[MPa].

The axial force exerts force (Fa) is also calculated using the equation:

$$F_a = A \cdot E \cdot \varepsilon$$

- The applied tightening torque Mt exerts on the bolt and the washer

Mt = Mb+ Mw

$$Mt = Fa * \frac{d2}{2} * \tan(\alpha + \rho) + F_a * \frac{dw}{2} * \mu w$$

Where dw is the washer contact diameter with the locking nut =12.5 mm, Knowing all the previously determined parameters of (α, ρ,$d2$) and the washer coefficient of friction (μ_w) can be calculated.

As shown in the tables of results each washer group with bolts has the same yield strength we have the number of the used washers represented in rows, and the columns express the number of tests as we progress in the measurements. The measured axial force and the calculated coefficient of friction are presented for each washer of its corresponding test.

Bolts Test	Washer 1		Washer2		Washer 3		Washer 4		Washer5	
M10 5.6	Fa	μw	Fa	μw	Fa	μw	Fa	μw	Fa	μw
Test 1	4289.36	0.14817	4408.55	0.14938	4097.89	0.15884	4145.943	0.14556	3955.78	0.129
Test 2	4624.32	0.14366	5671.54	0.14432	4694.51	0.1231	4338.96	0.13843	4561.93	0.10193
Test 3	5004.2	0.13045	4671.78	0.14299	5194.94	0.11232	4574.86	0.14571	5881.24	0.10591
Test 4	5481.12	0.12531	4551.53	0.13443	5681.54	0.11001	4861.32	0.14693	6229.16	0.10936
Test 5	5957.5	0.11385	4337.06	0.11284	5857.77	0.10447	5004.3	0.15805	6489.36	0.10552

Table 8 GroupA results of M10 (5.6 yield strength) of bolts with washers present axial force and coefficient of friction values

Bolts Test	Washer 1		Washer2		Washer 3		Washer 4		Washer5	
M10 5.8	Fa	μw	Fa	μw	Fa	μw	Fa	μw	Fa	μw
Test 1	4432.38	0.17002	4384.72	0.14851	4193.6	0.16001	4098.76	0.1844	4145.72	0.14968
Test 2	4680.21	0.16966	4433.4	0.14779	4288.9	0.12697	4373.758	0.14681	4756.9	0.13091
Test 3	5051.96	0.1525	4623.02	0.14666	4575.36	0.12239	4640.654	0.14434	5079.13	0.12529
Test 4	5623.88	0.12953	4716.4	0.1439	5716.6	0.11417	4813.183	0.14441	6434.1	0.11771
Test 5	6005.16	0.13466	5666.77	0.11436	6053.62	0.10513	Type text here 4919.55	0.12899	6567.55	0.1143

Table 9 Group B results of M10 (5.8 yield strength) of bolts with washers tests axial force and coefficient of friction values

Bolts Test	Washer 1		Washer2		Washer 3		Washer 4		Washer5	
M10 8.8	Fa	µw	Fa	µw	Fa	µw	Fa	µw	Fa	µw
Test 1	4527.7	0.17348	4480.04	0.18073	4146.42	0.16351	4217.91	0.19768	5480.9	0.15354
Test 2	4718.34	0.16598	4526.8	0.17968	4289.4	0.15986	4465.742	0.17911	5528.56	0.14864
Test 3	5290.26	0.14148	5713.4	0.1323	5337.44	0.1377	4670.68	0.16333	6148.14	0.12324
Test 4	5719.2	0.12513	5995.63	0.12548	5809.18	0.12236	4766	0.13189	6195.8	0.11818
Test 5	6052.82	0.11972	6481.76	0.11215	6142.9	0.11567	4813.66	0.12213	6529.42	0.10256

Table 10 GroupC results of M10 (8.8 yield strength) of bolts with washers tests axial force and coefficient of friction values

Bolts Test	Washer 1		Washer2		Washer 3		Washer 4		Washer5	
M10 10.9	Fa	µw	Fa	µw	Fa	µw	Fa	µw	Fa	µw
Test 1	4156.12	0.19817	4260.8	0.18125	3959.95	0.1823	4051.1	0.18651	3908.12	0.18241
Test 2	4289.67	0.15324	4360.89	0.17161	4529.1	0.17851	4289.797	0.17731	4481.15	0.13102
Test 3	4579.36	0.14678	4456.21	0.1707	5218.77	0.14657	4530.6	0.16841	5814.52	0.10134
Test 4	5242.6	0.13667	4632.55	0.13398	5291.6	0.14508	4816.183	0.16594	6147.84	0.10652
Test 5	5766.86	0.12005	5576.22	0.12427	5729.6	0.13788	4908.98	0.16375	6410.27	0.10185

Table 11 GroupD results of M10 (10.9 yield strength) of bolts with washers tests axial force and coefficient of friction values

The following graph represents the relation between the coefficient of friction values with all bolt groups of different yield strength, each single column representing the values of five tests for each bolt.

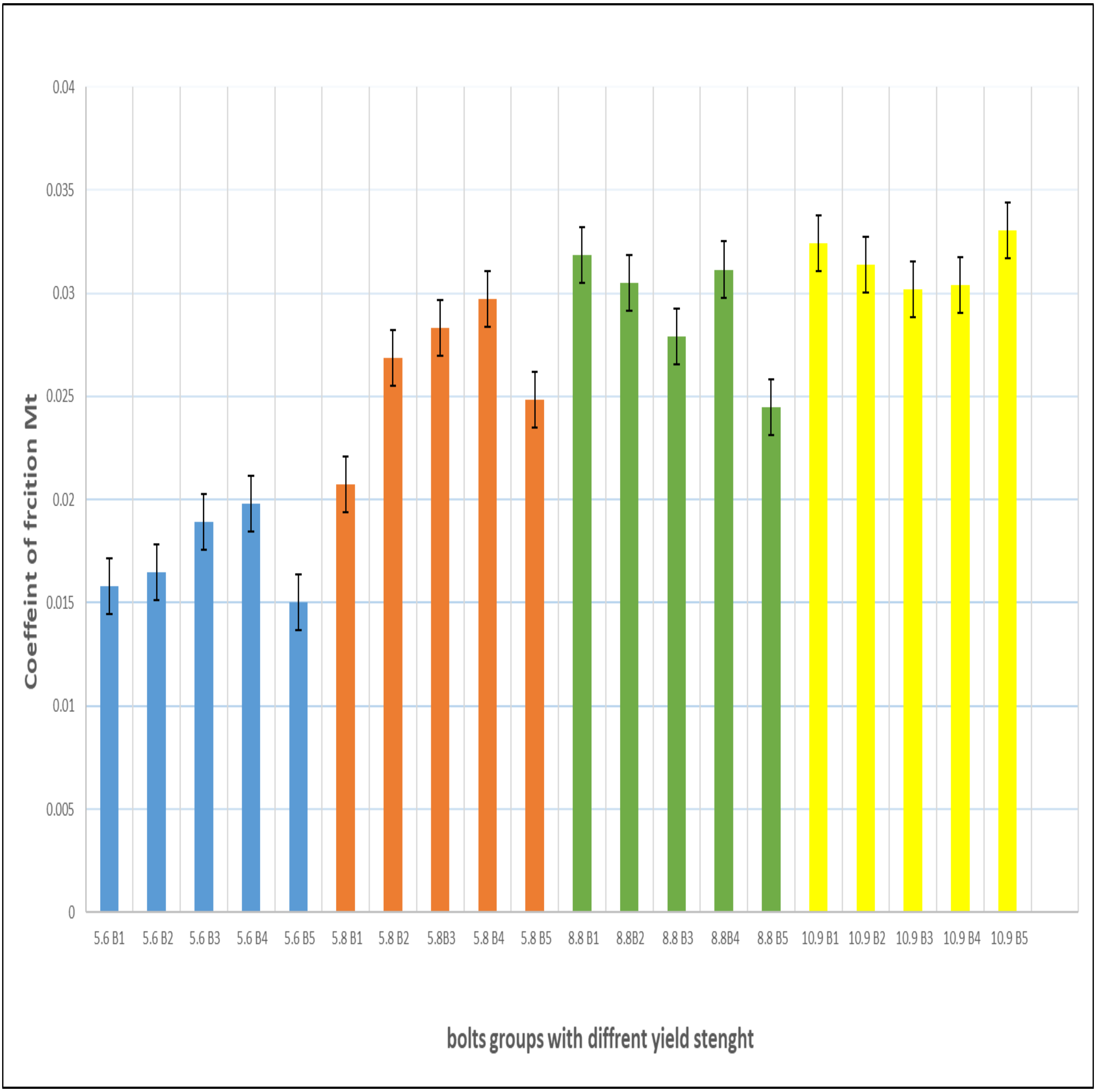


Figure 51 Standard deviation values of bolts groups with the coefficient of friction

The following graph represents the relation between the coefficient of friction values of washers with all washer groups of different yield strength, each single column representing the values of five tests for each washer.

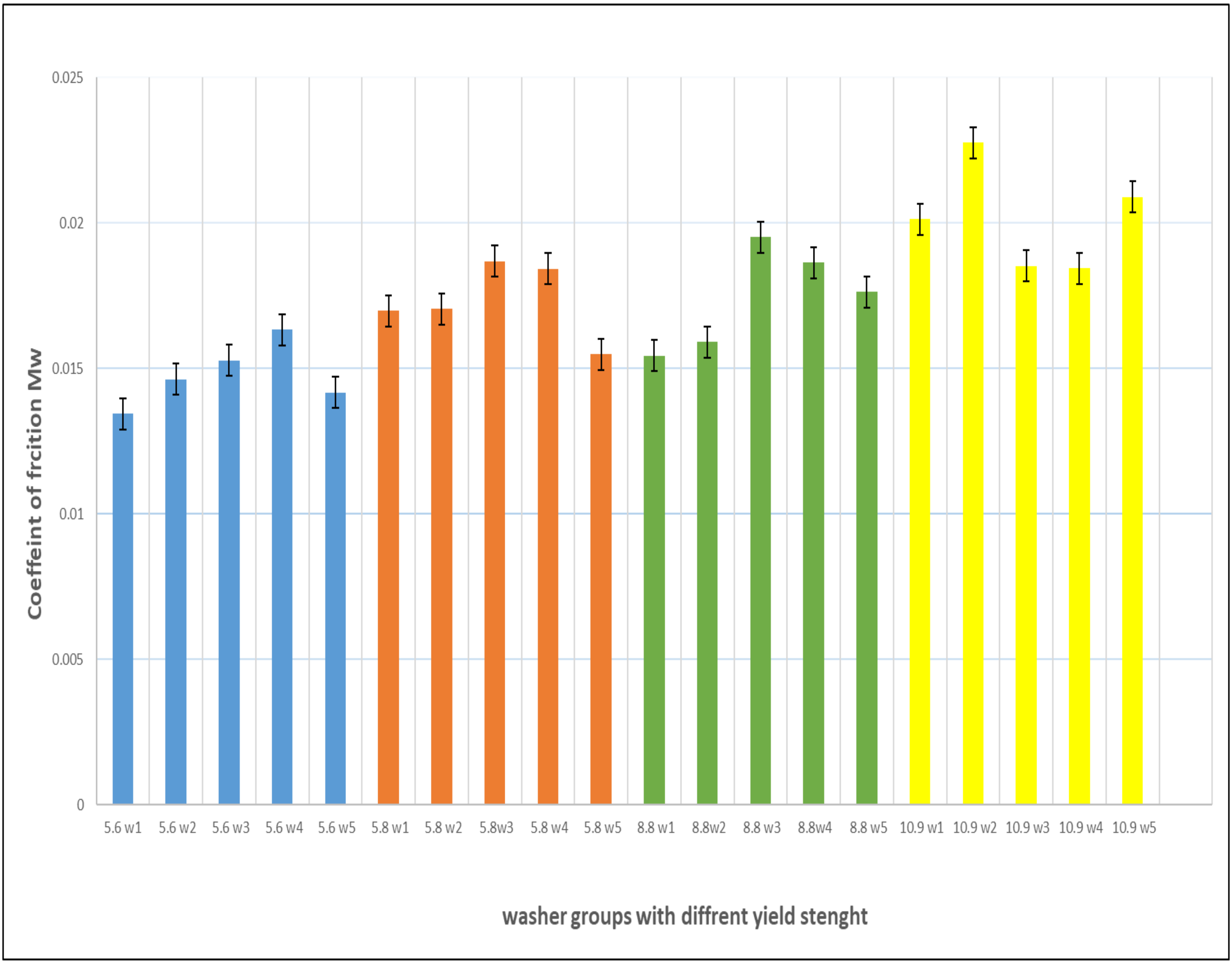


Figure 52 Standard deviation values of washer groups with the coefficient of friction

These tables represent the torque percentage values washer contact area MW and the bolt thread torque Mb calculated from the original applied torque used in tightening.

Bolts Test	%TORQUE VALUES PERCENTAGE									
M10 5.6	MW	Mb	MW	Mb	MW	Mb	MW	Mb	MW	Mb
Test 1	52.96213	47.03787	49.87804878	50.1219512	51.102411	48.897589	45.2914286	54.7085714	37.525968	62.474032
Test 2	51.360909	48.6390915	63.20922558	36.7907744	43.15789474	56.84210526	45.0551761	54.9448239	33.7508509	66.2491491
Test 3	50.400233	49.5997674	50.66921626	49.3307837	43.62604166	56.37395834	50.5494844	49.4505156	46.9044311	53.0955689
Test 4	53.235469	46.7645305	45.99025269	54.0097473	47.08478685	52.91521315	54.5238095	45.4761905	51.769552	48.230448
Test 5	52.521739	47.4782609	35.78431373	64.2156863	45.99659887	54.00340113	53.4637374	46.5362626	52.0655744	47.9344256

Table 12 5.6 Yield strength Group torque percentage of bolts torque MB and under thread torque MW

Bolts Test	%TORQUE VALUES PERCENTAGE									
M10 5.8	MW	Mb	MW	Mb	MW	Mb	MW	Mb	MW	Mb
Test 1	57.8	42.2	49.26453701	50.735463	51.102411	48.897589	57.9835664	42.0164336	46.7115793	53.2884207
Test 2	59.887875	40.112125	49.59951833	50.4004817	40.37846951	59.62153049	48.5106383	51.4893617	46.8930468	53.1069532
Test 3	59.203701	40.7962988	51.50224215	48.4977578	41.66666667	58.33333333	50.8212341	49.1787659	48.0321728	51.9678272
Test 4	55.705961	44.2940393	51.55568428	48.4443157	49.38702863	50.61297137	52.9208333	47.0791667	58.1147541	41.8852459
Test 5	62.389616	37.6103836	49.00386847	50.9961315	48.03368905	51.96631095	53.4637374	46.5362626	57.5543478	42.4456522

Table 13 5.8 Yield strength Group torque percentage of bolts torque MB and under thread torque MW

Bolts Test M10 8.8	%TORQUE VALUES PERCENTAGE									
	MW	Mb	MW	Mb	MW	Mb	MW	Mb	MW	Mb
Test 1	60.454545	39.5454545	62.47404844	37.5259516	51.102411	48.897589	64.4827586	35.5172414	65.1298701	34.8701299
Test 2	59.887875	40.112125	62.7831338	37.2168662	52.14285714	47.85714286	61.6548043	38.3451957	63.4782609	36.5217391
Test 3	57.372881	42.6271186	57.99024218	42.0097578	56.24913495	43.75086505	58.5726963	41.4273037	58.1428571	41.8571429
Test 4	54.636731	45.3632694	57.69276394	42.3072361	54.23478261	45.76521739	47.3809524	52.6190476	56.0194903	43.9805097
Test 5	55.386775	44.6132252	55.57971014	44.4202899	54.21202532	45.78797468	53.4637374	46.5362626	50.8064516	49.1935484

Table 14 8.8 Yield strength Group torque percentage of bolts torque MB and under thread torque MW

Bolts Test M10 10.9	%TORQUE VALUES PERCENTAGE									
	MW	Mb	MW	Mb	MW	Mb	MW	Mb	MW	Mb
Test 1	63.634973	36.3650272	59.356232	40.643768	51.102411	48.897589	57.962963	42.037037	54.4059406	45.5940594
Test 2	59.887875	40.112125	57.36496914	42.6350309	62.37477825	37.62522175	58.383823	41.616177	43.9251625	56.0748375
Test 3	51.012229	48.9877714	58.38911185	41.6108881	58.74172185	41.25827815	58.5837458	41.4162542	44.1048631	55.8951369
Test 4	54.70696	45.2930403	46.72208437	53.2779156	58.97724002	41.02275998	61.6010885	38.3989115	49.5748017	50.4251983
Test 5	52.692308	47.3076923	52.74748322	47.2525168	60.83378295	39.16621705	53.4637374	46.5362626	49.4067797	50.5932203

Table 15 10.9 Yield strength Group torque percentage of bolts torque MB and under thread torque MW

4.3. Mechanical effects on the thread contact area of M10 bolts due to the tightening and loosing.

The effect of repeated tightening and loosening on M10 bolts during many tests and experiments can lead to wear and thread damage over time, which can further affect the thread contact area and the joint's integrity.

The threads may become stripped or deformed to the point where they are no longer effective in creating a secure joint.

Thread damage can compromise the integrity of the bolted joint, reducing its ability to maintain the desired clamping force

This wear may result from friction and surface contact between the threads.

Wear can lead to a reduction in the thread contact area as the threads become rounded or damaged.

Deformation of the threads, especially if the tightening process is excessive or if there are inconsistencies in the torque applied, can also impact the thread contact area.

Figure 53 Frictional effects on the thread contact area of M10 bolt

4.4. Mechanical effects on the washer contact area due to tightening and loosing

The frictional effects during the experiments on the M10 flat washer's contact area can change during repeated tightening, loosening, and friction due to wear and deformation.

Wear may result from friction and repeated compression forces. It can reduce the contact area as the washer's surface becomes smoother or develops irregularities.

Using washers made from materials with good wear resistance and durability, such as stainless steel or hardened steel, can extend the life of the washer and maintain a more consistent contact

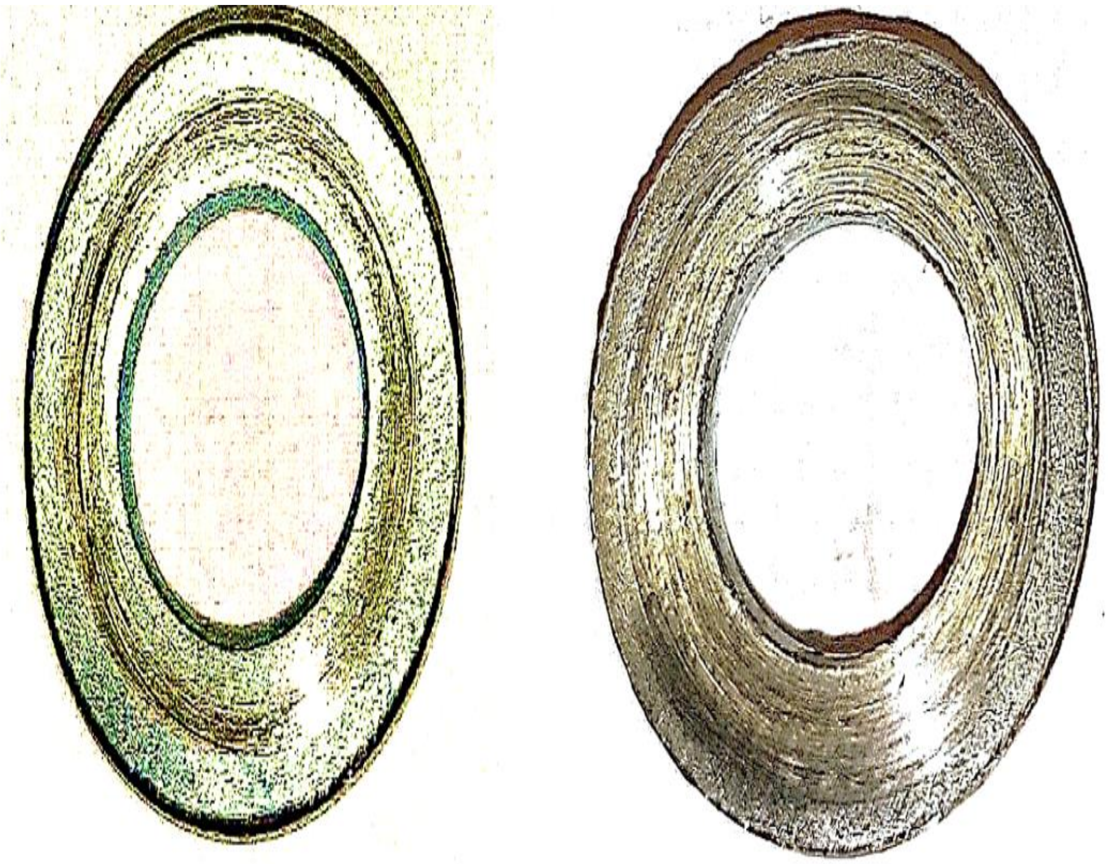


Figure 54 frictional effects on the washer contact area

5. Conclusion and Recommendations

The experiment aimed to evaluate the friction coefficients under various axial loads between M10 bolts and washers with varying yield strengths (5.6, 5.8, 8.8, and 10.9). The results analysis sheds important light on how these friction coefficients vary during additional testing. thorough examination of the data, emphasizing the patterns of increasing or decreasing friction coefficients and the related percentages and rates of change.

Analyzing the bolt coefficients of Friction results shows that the pretension force is gradually increased in every same yield strength bolts group test with the screwing times during the experiment tension tests within a specific torque value as its directly affected by the increases in the elongation values depending on the used calculation formula ($F_a = A \cdot E \cdot \varepsilon$).

In the four bolt groups with different yield strengths when applying the same torque for all bolts, results show the bolts with the lower yield strength will experience a greater elongation or deformation than the higher yield strength bolts under the same certain torque but on the other side of view the results show that the coefficient of friction values getting increased in the higher yield strength bolts groups which means that under the same applied torque of all bolts, in the lower yield strength bolts group the torque mostly goes in tension and deformation but in the higher yield strength bolts the torque mostly leads to the higher coefficient of friction reults also in the washer tests with the same bolts groups show a similar attitude.

Bolts Results show that the percentage increase of values of the coefficient of friction (μt) was increased by approximately 51.08% in the higher yield strength bolts groups (10.9) than the lower yield strength bolts groups (5.6) coefficient of friction values under the same applied torque and same test conditions.

Results show that the torque percentage values of torque exerted in the washer contact area M_W range from 50.4% to 63.5 % which is always greater than the range of the torque exerted on bolt M_b values from 36.5% to 49.6% of the original applied torque used in tightening.

It is strongly recommended to reduce friction in M10 bolt threads and on washer surfaces, is to lubricate the contact areas between threads, and the contact surface between the nut and the upper surface of the washer, and ensure that both the bolt threads and washer surfaces are free from burrs, irregularities, or sharp edges can help reduce friction.

6. Summary

This experiment focused on measuring friction coefficients under the same certain applied torque for various M10 bolts with different yield strengths and for the M10 flat washers under the same conditions and the same applied torque to evaluate the extent of their impact and the rate of their change and the relationship between the measuring values also finding the percentage of applied torque on the bolts and washers from the original torque value. figuring out the impact of friction on the bolt thread and washer surfaces.

1. The methodology employed a precise measurement device setup to ensure accurate data collection. after the M10 bolt heads were cut to fit the setup, bolts with the same yield strength were grouped into four groups. each group contains five bolts had yield strengths of 5.6, 5.8, 8.8, and 10.9. the bolts were numbered for the testing process, and a specific torque value of 15 Nm was selected to analyze the relationship between the pretension force and the coefficient of friction. the presented measurement device can properly determine bolt pretension and elongation values during the tightening operation of threaded connections.

2. The measured data were achieved with the help of strain gauges, then processed by Data logger HBM Spider 8, and visualized by the Catman software. Afterward, data is collected from the software, which visualizes torque and deformation during the tightening process. A constant torque reference value is established with a tolerance of ± 3 %; since the measurement cannot be an absolute value.

3. In The M10 bolt test using the bearing supportive connection the axial force is calculated with the appropriate formula, introducing the correlation with the screwing times five times for every single bolt in each group of yield strength and evaluating the coefficient of friction of bolts thread also repeating the same process for new same bolts groups with washers instead of bearing using the proper equations to evaluate and analyze the value of the coefficient of friction of washers regarding the change in pretension force as a comparison.

4. The results for bolt testing showed variations in axial force and coefficient of friction for different bolts and different tests. For bolt thread coefficient of friction (μt) calculations, the axial force (fa), and the tightening torque were evaluated using the pitch diameter (d2) and friction angle (ρ), with the pitch of M10 bolts and the friction angle determined using specific equations.

5. Washer testing followed a similar approach, with a focus on the coefficient of friction (μw). The same measurement setup was used. Washer coefficients of friction were calculated using the tightening torque (Mt), and washer contact diameter (dw).

6. The study also explored the mechanical effects on the thread contact area of M10 bolts due to repeated tightening and loosening, which could lead to wear and deformation, affecting the integrity of the joint. Similarly, the washer's contact area was examined, as wear and friction could change it over time.

7. Lastly, this experiment aimed to provide reliable data for coefficients of friction for M10 bolts and washers, considering various yield strengths. The methodology involved precise measurement setups, data collection, and careful analysis of the results. These findings are valuable for understanding the behavior of these mechanical fasteners under different conditions, which can have implications for engineering and design applications.

DECLARATION

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Year of publication: 2023

Department: Mechanical Engineering

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