EFFECT OF HOLE SIZE, SHEET THICKNESS AND MATERIAL TYPE TO THE PERFORMANCE OF THE SELF-CLINCHING FASTENER

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LIST OF SYMBOLS

i	Variable
mm	Millimetres
Nm	Newton meter
n	Number of observation
psi	Pounds per square inch
s	Second
y	Observed data

LIST OF ABBREVIATIONS

DC	Direct Current
DRO	Digital Read Out
EDM	Electrical Discharge Machine
HB	Higher the Better
M8 × 1.25	M = Metric thread designation
	8 = Nominal diameter, in millimetres
	1.25 = Pitch (distance from thread to thread), in millimetres
MS	Mild Steel
S/N	Signal to Noise

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ABSTRAK

Kebolehpercayaan pengikat rangkum sendiri dalam penggunaan bergantung kepada beberapa faktor, bermula dengan ukuran saiz lubang yang betul, ketebalan dan kekerasan panel perumah. Pemasangan dan reka bentuk pengikat yang tepat dan juga aplikasi di mana pengikat tersebut digunakan juga memainkan peranan. Pengikat rangkum sendiri sesuai untuk digunakan dengan kepingan logam nipis dalam pengeluaran komponen kereta serta peranti komunikasi moden seperti telefon pintar dan komputer. Kekuatan mutakhir pemasangan pengikat rangkum dengan bahan dasar perlu dipastikan teguh untuk menghasilkan pemasangan yang kukuh. Dalam projek ini, kesan geometri lubang, ketebalan dan jenis bahan panel perumah telah dikaji pada prestasi salah satu pengikat rangkum sendiri iaitu nat dengan menjalankan ujian kilasan pada panel yang dipasang bersama nat tersebut. Ujian tersebut dijalankan pada lima peringkat parameter. Rig ujian juga telah direka untuk memegang teguh panel perumah semasa ujian kilasan pada mesin kilasan separa auto. Ujian kilasan-keluar dilakukan sehingga nat berputar atau bergerak di dalam lubang panel perumah dan nilai kilasan untuk setiap panel ujian direkod menggunakan perakam PicoLog. Tahap kepentingan dan kombinasi parameter yang optimum untuk ujian kilasan-keluar dianalisis berdasarkan kaedah Taguchi. Analisis tersebut mendedahkan bahawa diameter lubang adalah parameter yang paling penting untuk prestasi nat tersebut bagi kedua-dua jenis panel perumah iaitu keluli ringan dan Aluminium 5052. Dalam membandingkan kedua-dua bahan panel, jenis bahan menunjukkan kepentingan yang paling tinggi berbanding dengan ketebalan panel dan diameter lubang. Di samping itu, bagi panel keluli ringan, gabungan parameter yang optimum untuk prestasi maksimum nat dalam penggunaan adalah pada ketebalan panel 3 mm dan diameter lubang 8.71 mm. Sementara itu, untuk panel perumah Aluminium 5052, ketebalan 3 mm dan diameter lubang 8.83 mm. Untuk analisis gabungan panel perumah keluli ringan dan Aliminium 5052, prestasi maksimum dapat dicapai pada panel perumah keluli ringan pada ketebalan 2 mm dan diameter lubang 8.71 mm.

EFFECT OF HOLE SIZE, SHEET THICKNESS AND MATERIAL TYPE TO THE PERFORMANCE OF THE SELF-CLINCHING FASTENER

ABSTRACT

The reliability of a self-clinching fastener in an application depends on several factors, starting with a properly sized hole, the thickness and hardness of the host panel. Correct installation and design of the fastener as well as the application wherever the fastener is applied also play a role. Self-clinching fasteners are well-suited for working with thin metal sheets such as in the production of automobile parts as well as modern communication devices like smartphone and computers. The ultimate strength of the mating clinching fastener with base material needs to be ensured sturdy to produce a strong assembly. In this project, the effect of holes geometries, sheet thickness and material type of the mating panel was studied on the performance of one of the self-clinching fasteners which are nut by conducting a torque-out test on the mating panel and nut. The testing was conducted at five level factors of parameters. A test rig was fabricated to firmly hold the panels during the torque-out test on the semi-auto torsion machine. The torque-out test was performed until the nut rotate or fail within the panel and torque values for each test panels were recorded using PicoLog recorder. The level of significance and optimal combination of parameters for the torque-out test were analysed based on Taguchi Method. The analysis revealed that hole diameter is the most significance parameters to the nut's performance for both Mild Steel and Aluminium 5052 host panel. In comparing both materials of panel, material types shows the highest significance compared to sheet thickness and hole diameter. In addition, for mild steel host panel, the optimal combination of parameters for maximum performance of the nut in its application are on the panel thickness of 3 mm and hole diameter of 8.71 mm. While, for Aluminium 5052 host panel, thickness of 3 mm and hole diameter of 8.83 mm. For the combined analysis of Mild Steel and Aluminium 5052 host panel, the maximum performance can be found on Mild Steel host panel with thickness of 2 mm and hole diameter of 8.71 mm.

CHAPTER 1

INTRODUCTION

1.1 Project Background

The self-clinching fastener is a device to joint sheet metal and usually threaded. When inserting into ductile metal, it will displace the host material around the mounting hole and will cause the sheet metal to cold flow into a specially designed annular recess in the shank of the fastener (Figure 1.1).

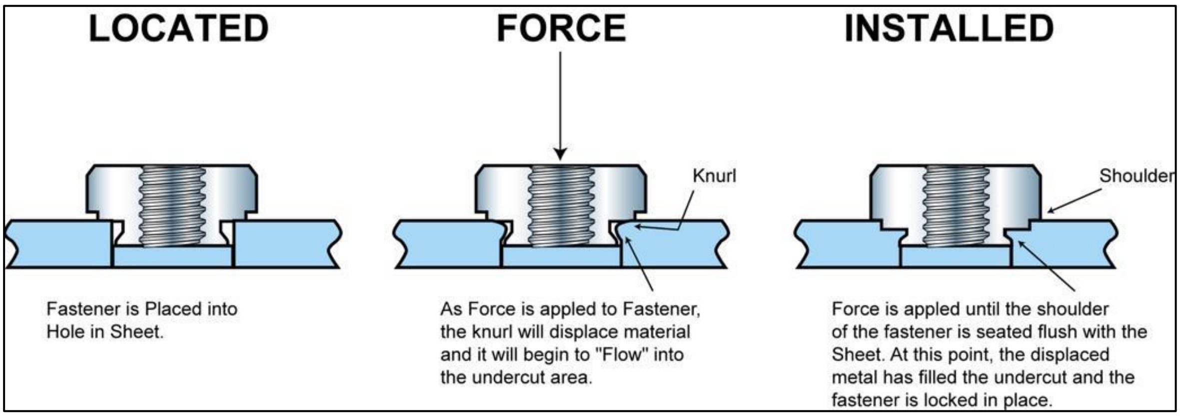

Figure 1.1: Self-clinching nut installation process

For designing the self-clinching fasteners, it is necessary to design the fasteners with features that will prevent the fasteners from rotating in the host material when it has been properly installed such as serrated clinching ring to improved torque-out which is a rotational force and also to improve push-out resistance. Therefore, self-clinching fasteners become a permanent part of chassis, panel, bracket, or other items which they are installed. Removal action of the fastener will result in the failure of the metal or the fasteners(PennEngineering, 2018; Roca & Cited, 2006).

Standard self-clinching fasteners usually require extremely tight tolerances for the fastener itself and the hole into which the fastener will be installed. Tight tolerances exist for both of the size of the hole and the thickness of the panel. For instance, there must be sufficient material to cold flow into the various recesses and features of the self-clinching fastener to secure the fastener to the sheet and provide enough resistance to the external force.

This is because, if a self-clinching fastener is squeezed into an opening that is marginally too large for the fastener, there might be inadequate material to flow into the recesses and features of the fastener. Hence, it can cause the connection between the fastener and the panel to be weaker than the anticipated result and the fastener may fail during a normal service (Roca & Cited, 2006).

Self-clinching fasteners are commonly used wherever there is a need for strong internal threads to attach components or fabrication assembly such as automotive and appliance industries to secure various type of components to metal panels. Screws or bolts are threaded into the clinch nuts and tightened to prescribed torque values. During the installation and service, the clinch nuts must have sufficient rotational resistance to keep them from rotating relative to the metal sheets when external forces such as vibration or other twisting forces are applied (W. Richard Pamer & Stanley H. Umbel, 2002).

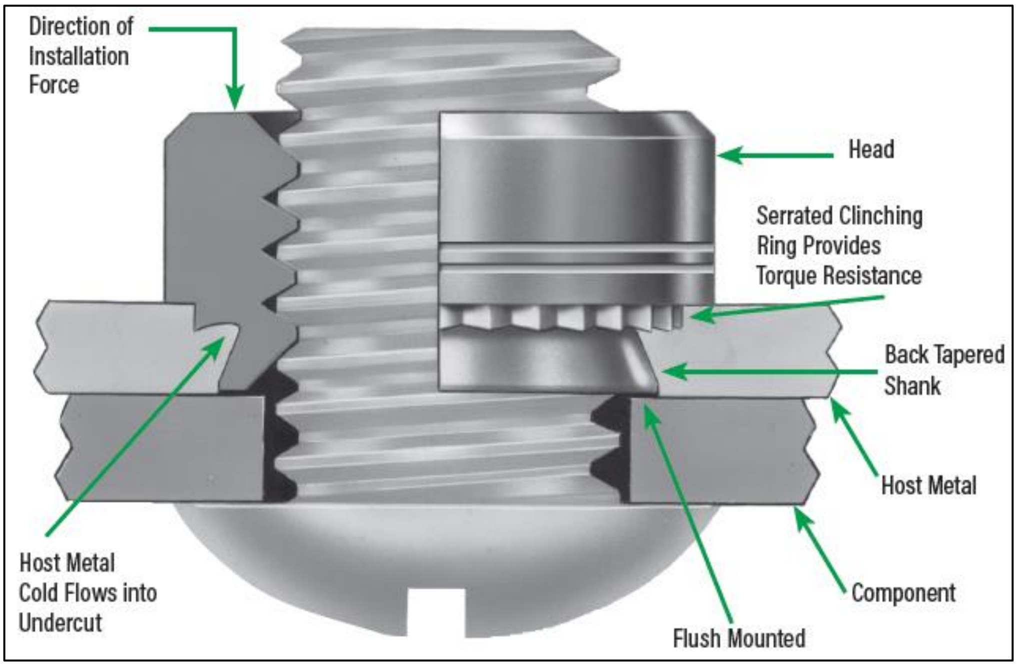

Figure 1.2: Anatomy of the typical self-clinching nut (PennEngineering, 2018).

The reason for the study is to improve fabrication assembly by determining the ideal geometries to securely clinch the fastener. In addition, there is a need for a self-clinching fastener that has high resistance to the external force, so that it can be attached to the material of varying thickness, and can be attached to holes of the metal sheets (Roca & Cited, 2006).

There are four classifications of self-clinching fasteners which are nuts, studs, spacers/standoffs, guide pin and captive screw. However, for this project, the study and investigation will be based on a self-clinching nut only. The purpose of this project is to investigate the effect of holes geometries, sheet thickness and material type to the performance of self-clinching nut by determining the optimal geometries for all parameters using the Taguchi Method.

Figure 1.3: Self-clinching fasteners from left-to-right: standoff, nut, guide pin, stud and captive screw (Summers, 2011).

1.2 Problem Statement

The self-clinching nut is used on thin sheet metal in the assembly process and it provides a secure fastening because the nut is designed to have good pullout and torque loads when installed into the metal sheet. The performance of self-clinching nut relies on few factors such as hole size, sheet thickness and material type. Therefore, to ensure optimal performance of the self-clinching nut and improve the fabrication assembly of metal parts, optimal combination of parameters that have the most influence on the nut's performance should be investigated.

1.3 Objectives

The objectives of this project are: -

1. To investigate the effect of hole geometry, sheet thickness and material type of panel sheet to the performance of self-clinching nut.
2. To determine the level of significance of geometrical parameters to the performance of self-clinching nut by using the Taguchi Method.
3. To determine the most optimal combination of parameters that can resist the highest torque-out force on the mating nut and panel for Mild Steel and Aluminium 5052 host panel.

1.4 Scope of Project

In this project, the holes geometries for the self-clinching nut will be prepared based on recommended size and variation is randomly determine between the recommended size range. Therefore, to get the desired size EDM Wire Cut was used. The self-clinching nut is manually pressed on the sheet metal. The pressed nut on the metal sheet. The pressed nuts on the metal sheets then will undergo a torque-out test on Semi-Auto Torsion Machine for performance evaluation. There are only two types of easily available materials are included in this study that are Mild Steel and Aluminium 5052.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

A self-clinching fastener for insertion into ductile sheets from a variety of thickness has improved push out and torque-out resistance. The self-clinching fastener includes a plurality of radial projections and spline teeth that inserted into the ductile sheets, inflicting the material to cold flow into a recess, thereby permanently clinching the self-clinching fastener to the ductile sheet (Roca & Cited, 2006).

2.2 Type of Self-Clinching Fastener

Self-Clinching fasteners are suitable for connection to a panel or chassis that have a shank with diameter less than the head portion of the fastener (Osborn, Pua, Blaess, Wang, & Dayton, 2016).

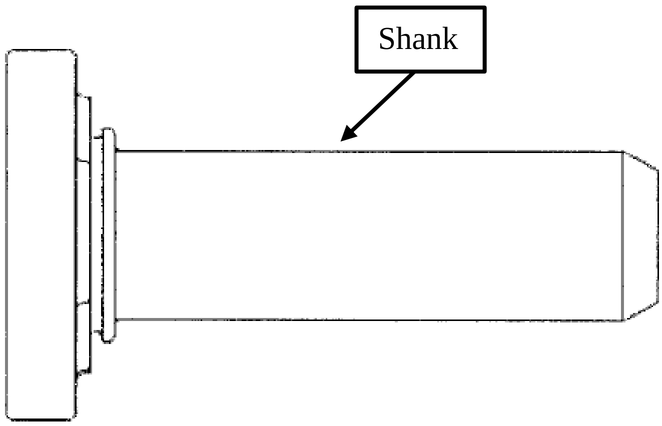

Figure 2.1: Side view of self-clinching fastener (Osborn et al., 2016).

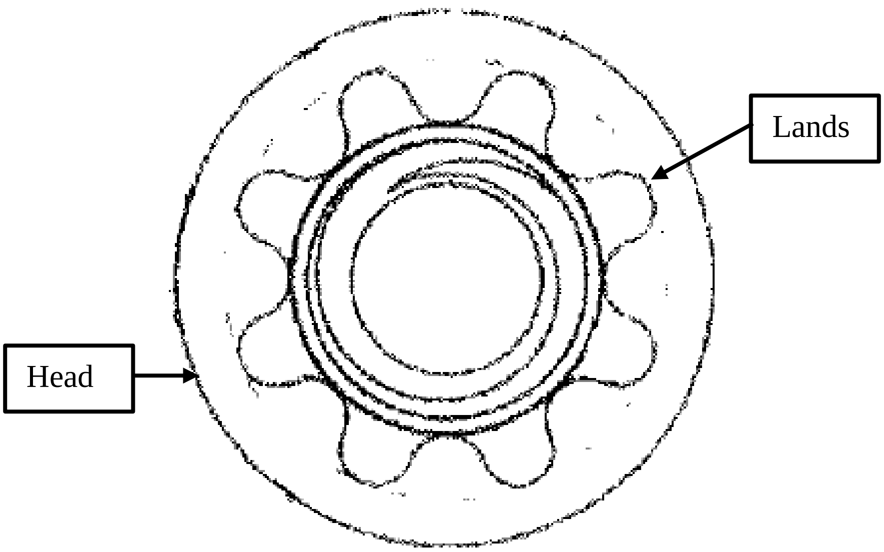

Figure 2.2: Bottom view of self-clinching fastener (Osborn et al., 2016).

A headed screw driven into the internal thread of the fastener to join the riveted subassembly was disclosed and this reference shows leads of a busbar attached to a printed circuit board with the use of a rivet nut type fastener (Adachi, Takahama, Kazama, Hayashi, & Sakita, 1991).

A new design for an internally threaded fastener that is similar to rivet nuts then was invented which includes both characteristics of rivet and nut. The joined parts become trapped or riveted and collapsible middle portion of the fastener shank being deformed by compression when a threaded screw inserted into the fastener shank is tightened (Phillips II, 1994).

2.3 Type of Test

There are three tests applicable to determine the reliability of self-clinching fastener in service. The tests are the torque-out test, pushout test, and pull-through test. The torque-out test is a test that determines the fastener's ability to resist rotation within the panel or chassis. This test usually made at the head of the fastener with values exceeding the ultimate torsional strength of the mating nut and screw.

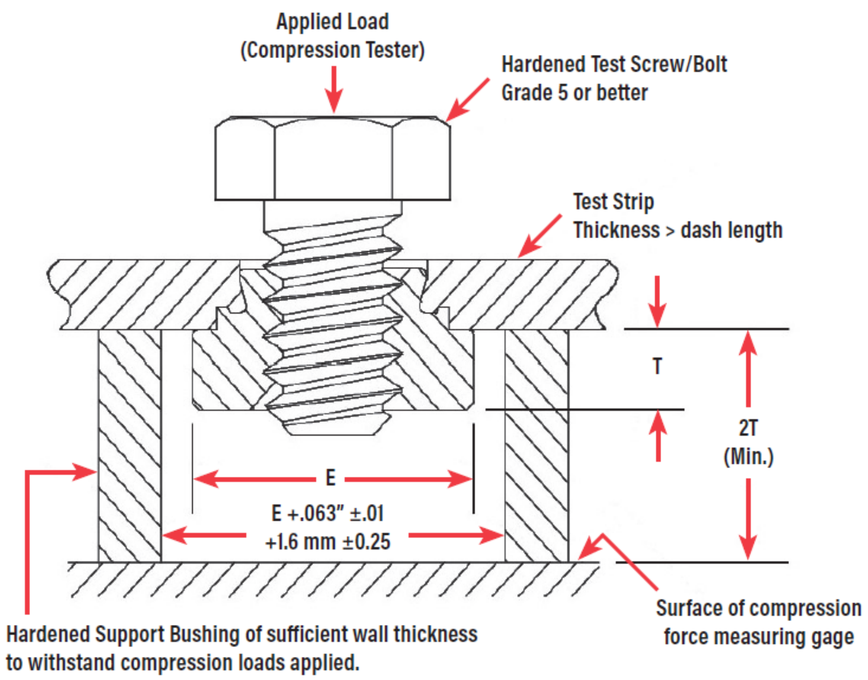

Figure 2.3: Pushout test for self-clinching fastener [1].

The second reliability measure which is pushout (Figure 2.3) that indicates the axial resistance of the fastener to remove it from the panel opposite to the direction from which the fastener was installed while the pull-through test is a test to evaluate the ability of the fasteners to resist pulling through the panel when a clamping torque is applied (PennEngineering, 2018).

2.4 Application of Taguchi Method in Reliablity Evaluation

Taguchi method is a statistical method that is developed by Genichi Taguchi. The intention of this method is to improve the quality of manufactured products or goods and also applied to engineering purpose, marketing, biotechnology and advertising. Taguchi started to develop new methods to optimize the process of engineering experimentation. He believed that the best way to improve quality was to design and build it into the product. He developed the techniques which are now known as Taguchi Methods. The Taguchi way to deal with engineering's quality has spotted a lot of accentuation on limiting variety as the principal methods for improving quality. The thought is to design goods and process whose performances is not influenced by outside conditions and to build this in amid of development and design stage using the experimental design. The method involves a set of tables that allow the main variables and interactions to be examined in a minimum number of evaluations. It is additionally brought up that the Taguchi Method is entirely good with the human-centered quality assessment approaches that are coming up (Karna & Sahai, 2012).

2.5 Fasteners Installation Do's and Don'ts

A mounting hole with the specified size is required before installing the fastener onto the panel material. The mounting hole may be drilled or punched and the hole should not have broken edges or be chamfered. The fastener should be installed into the punch side of the panel material and the distance between the edge of the panel should not be too close to the centerline of the holes. Installing the nut too close to the edge can cause the panel to bulge or blow out. Besides, the shank of the fastener should be ensured within the hole before applying installation force between parallel surfaces. Sufficient installation force should be applied to totally embed the clinching ring of the fastener around the hole and also to bring the fastener's shoulder squarely in contact with sheet (PennEngineering, 2018).

CHAPTER 3 p

RESEARCH METHODOLOGY

3.1 Overview

The self-clinching nut is used on a thin sheet in an assembly process and it provides a secure fastening when installing into metal sheet. However, to ensure an optimal fastening and strong assembly parts, geometries such as the diameters of the holes on which the nut is secured also need consideration. An optimum hole geometry needs to be investigated to ensure high torque resistance between the metal sheet and the nut. Therefore, a torque-out test was conducted on a different type of metal plates that has different size of thicknesses.

3.2 Parameters Selection

Aluminium 5052 and Mild Steel was selected as the host panel to secure the nuts and for each type of metal plates, the thickness used are 2 mm and 3 mm. The thicknesses of the plates were chosen based on the standard that is recommended by PennEngineering® for M6×1 self-clinching nut (PennEngineering, 2017). The recommendation is, the thickness of the metal sheets should not be less than the shank length of the self-clinching nut. The shank length is the length from the nut head to the tail it is also a portion of the fastener which is embedded in the panel material.

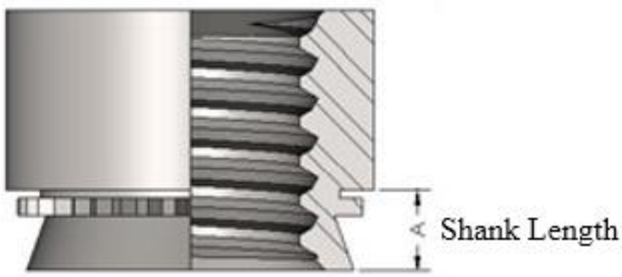

Figure 3.1: Shank length of the self-clinching nut

Besides, five different holes of diameters were selected, also based on the PennEngineering® handbook of self-clinching nut. The selected holes diameters are 8.67 mm, 8.71 mm, 8.75 mm, 8.79 mm and 8.83 mm. Therefore, there is a total of 20 pieces of testing samples. Table 3.1 shows the parameter's value used for host panels.

Table 3.1: Parameters value for the host panel

Type of Host Metal	Thickness of Host Metal (mm)	Hole Diameter (mm)
Mild Steel	2.00	8.67
		8.71
		8.75
		8.79
		8.83
	3.00	8.67
		8.71
		8.75
		8.79
		8.83
Aluminium 5052	2.00	8.67
		8.71
		8.75
		8.79
		8.83
	3.00	8.67
		8.71
		8.75
		8.79
		8.83

3.3 Design of Test Rig

Next, a test rig as in Figure 3.2 for use at torsion machine was designed using SolidWorks. The test rig is to hold the test sheet firmly while conducting the torque-out test and ensure that it is not rotating together with the self-clinching nut.

Some considerations were taken during designing the test rig such as the size of the host panel, and the connection mechanism of the test rig with the semi-auto torsion machine. After that, the designed test rig was fabricated so the host panel.

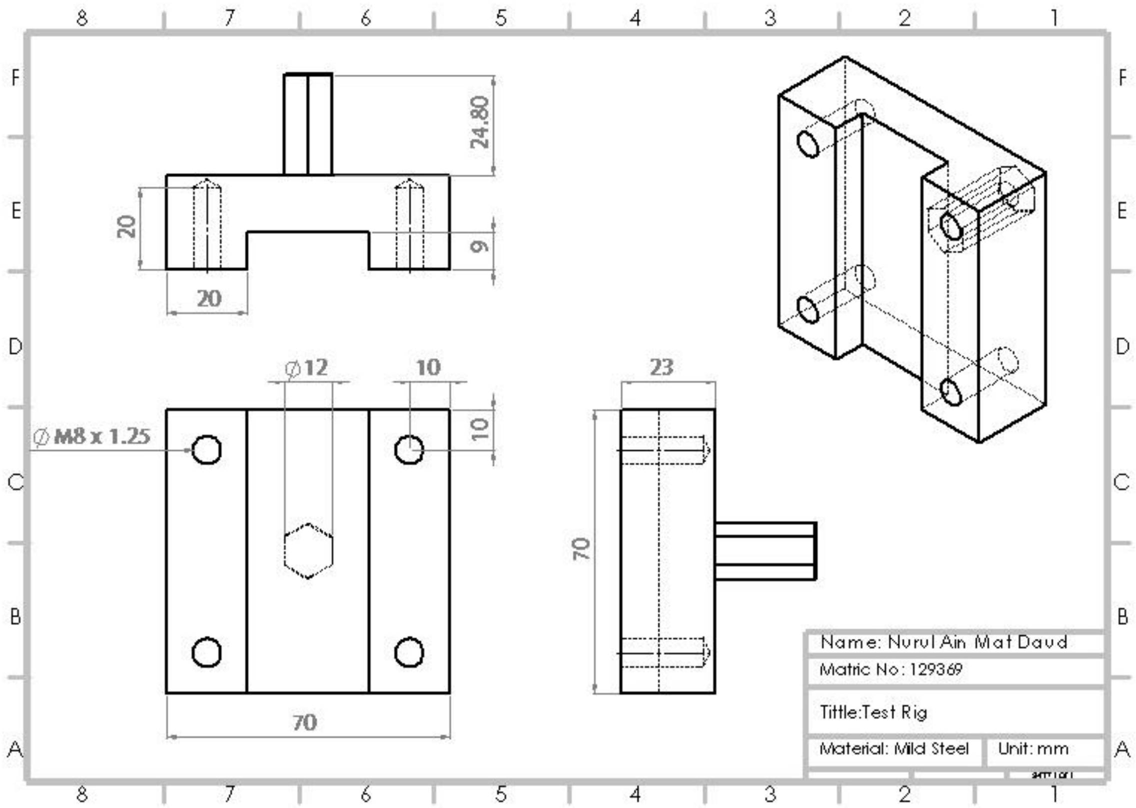

Figure 3.2: Drawing of the test rig

3.4 <u>Fabrication of The Test Rig</u>

A mild steel block with a thickness of 25 mm was cut to size approximately 75 mm × 80 mm using Horizontal Band Saw machine as shown in Figure 3.3.

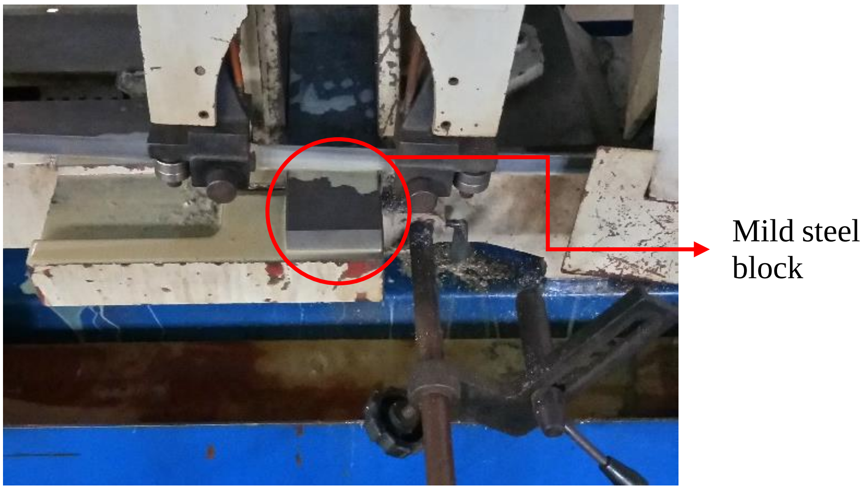

Figure 3.3: Process of cutting mild steel block using Horizontal Band Saw

Next, the block was machined to the required size of 70 mm × 70 mm using milling machine and then was machined again to create a 70 mm × 30 mm slot with a depth of 9 mm on its surface.

Figure 3.4: Milling Process to the size of 70 mm × 70 mm

Four 6.80 mm holes diameter (M8 × 1.25) on each surface's corners of the block was drilled and the holes were tapped using hand tapper to a depth of 20 mm as shown in Figure 3.5. The drilling process requires very high precision and focus to ensure the distance between each hole on the test rig block is equivalent to the distance between each hole on host panels. This is to make sure that the holes will align when screwed them together.

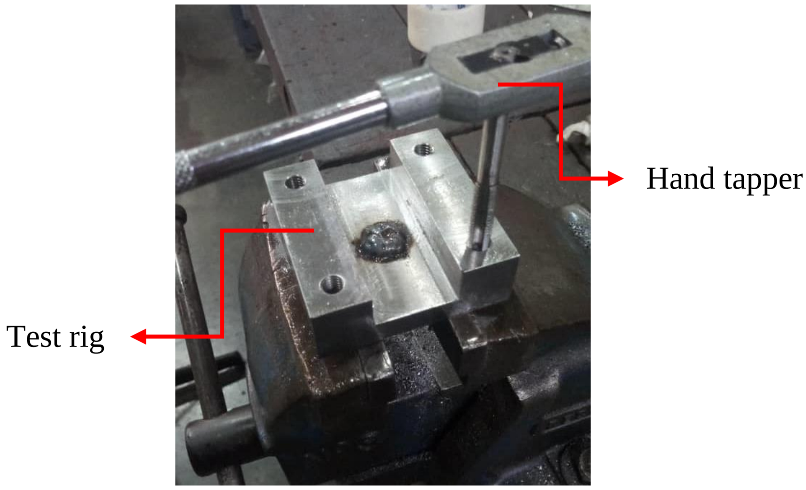

Figure 3.5: Tapping process (M8 × 1.25) using Hand Tapper

Then, a 1/2” hexagon bar (as an adapter) was weld on the back surface of the test rig. The hexagon bar and the test rig body was ensured to be 90 degrees to prevent it from being tilted when placing it on semi-auto torsion machine.

3.5 Fabrication of Host Panel

Metal plates with thickness and types mentioned in Table 3.1 were cut with size approximately 70 mm × 70 mm. Four through holes of M8 was drilled using conventional milling machine at each corner of the plates and a 5 mm holes were drilled at the centre of the plates as a requirement to cut the required holes geometries using EDM Wire Cut machine.

To ensure the drilled holes on the host panel align with the holes on the test rig, a milling machine with Digital Read Out (DRO) numeric display installation has been used. The DRO features make the scaling of the centre of the holes coordinate more accurate and efficient.

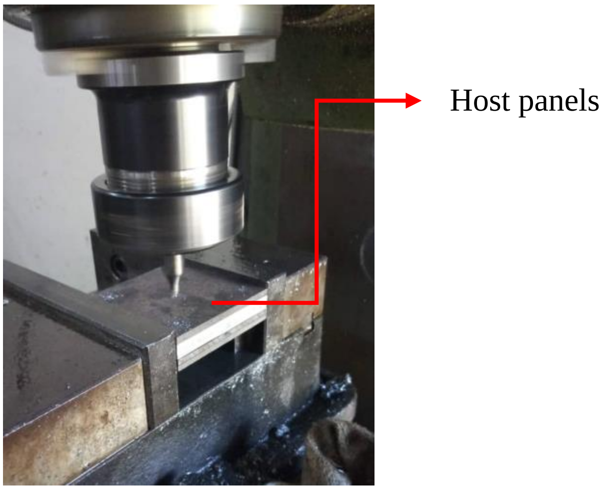

Figure 3.6: Process of marking the centre of holes before the drilling process

Then, the hole diameters as mentioned in Table 3.1 was drilled using EDM Wire Cut process. Figure 3.7 and Figure 3.8 show the fabricated host panel of Mild Steel and Aluminium 5052 respectively. The sharp edges around the metal plates and it's hole were filed to ensure each plate are flat when bound together for the EDM Wire Cut process.

Figure 3.7: Host Panel for Mild Steel

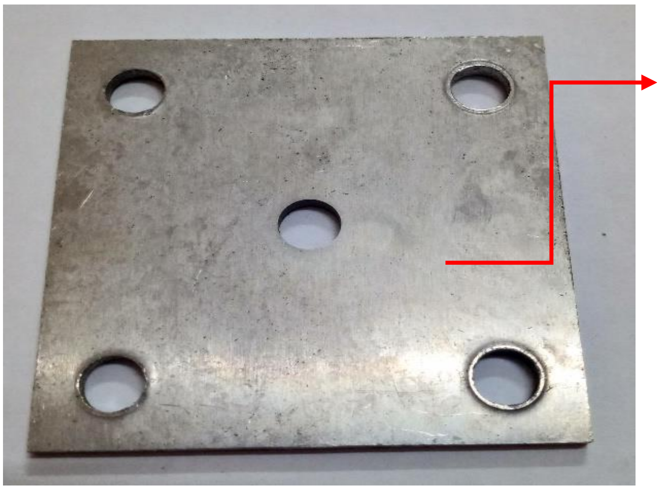

Figure 3.8: Host panel for Aluminium 5052

3.6 Inspection on Holes Diameter of The Host Panels

Then, the drilled holes were inspected to check whether there is a deviation of diameters from the required dimension of holes. The inspections were conducted using Internal Micrometer with a resolution of 0.01 (Figure 3.9) mm and followed by pressing the nut into the drilled holes on the host panels.

Figure 3.9: Internal Micrometer

3.7 Pressing Process

The self-clinching nut was manually pressed into the drilled holes using a Hydraulic Press machine (Figure 3.10) and approximately 300 psi of pressure was required to press the nuts into mild steel plates while approximately 200 psi was needed to press the nuts into Aluminium 5052 test sheets.

Figure 3.10: Hydraulic press machine

Before pressing the nuts, an attempt of pressing the nuts was carried out to identify enough force required to totally embed the knurling, so the shoulder of the nut is squarely in contact with the test sheet. As a result, 200 psi and 300 psi are required for Aluminium 5052 and mild steel respectively. The installed nut on the host panel is shown in Figure 3.11.

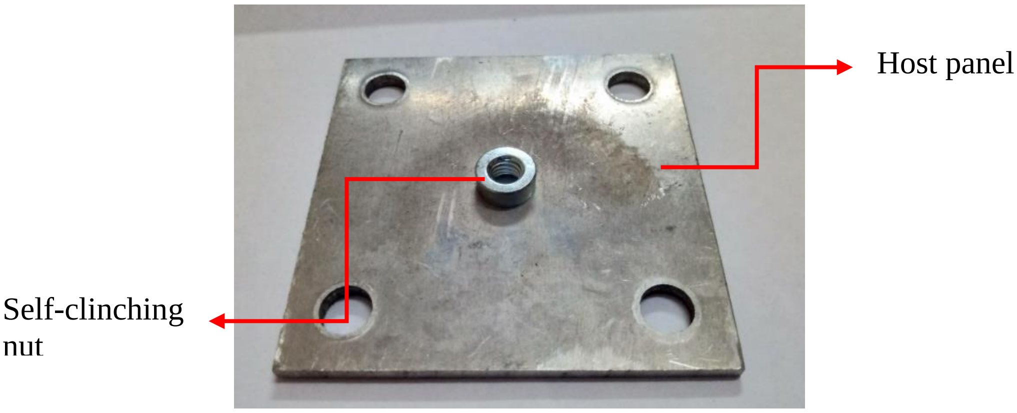

Figure 3.11: Host panel with self-clinching nut installation

3.8 Torque-out Test

Then, the torque-out test was conducted on each host panels with different thicknesses and holes diameters using a Semi-auto Torsion machine (Figure 3.9). The torque value then was recorded using a PicoLog recorder. The machine setup for the test is shown in Figure 3.10.

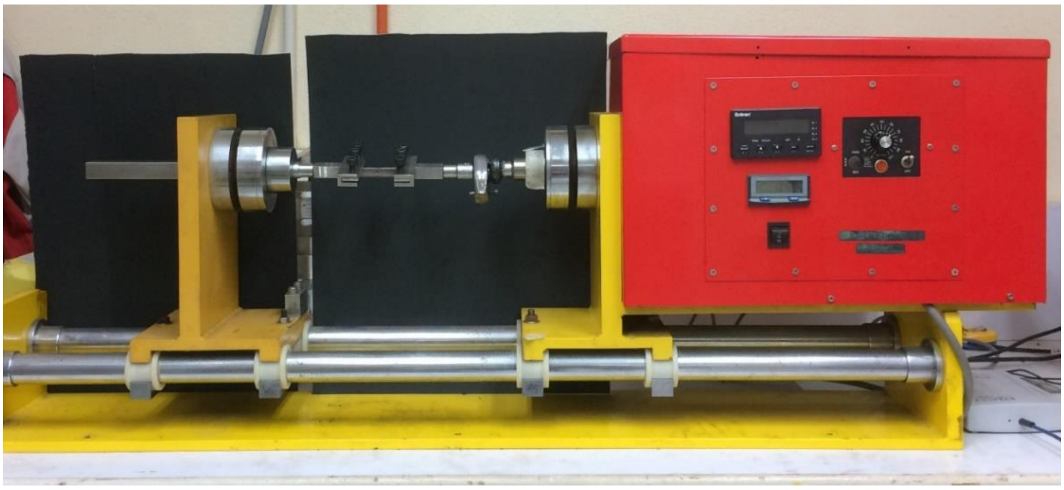

Figure 3.12: Semi-auto Torsion machine

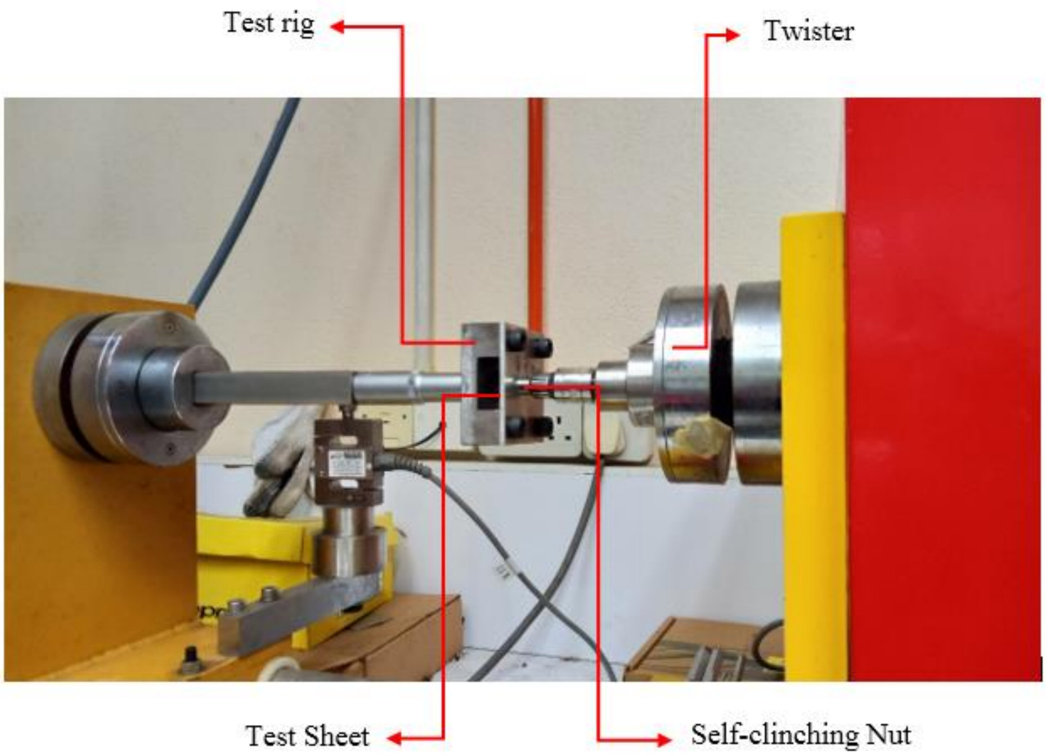

Figure 3.13: Machine set-up configuration for torque-out test

The torque applied was measured using “S” beam type tension/compression load cell (Figure 3.11) and the load cell was calibrated using PicoLog software installed in the computer before twisting the nut.

Figure 3.14: “S” beam type tension/compression load cell

Typical test set-up for torque-out testing for the self-clinching nut is shown in Figure 3.12. An M6 × 1.25 bolt was inserted into the nut holes with a washer placed between the nut and bolt to prevent the neck of the bolt from contacting the nut’s thread. The torque was applied in a clockwise direction as shown in Figure 3.12 with DC motor speed of 40% for all specimens.

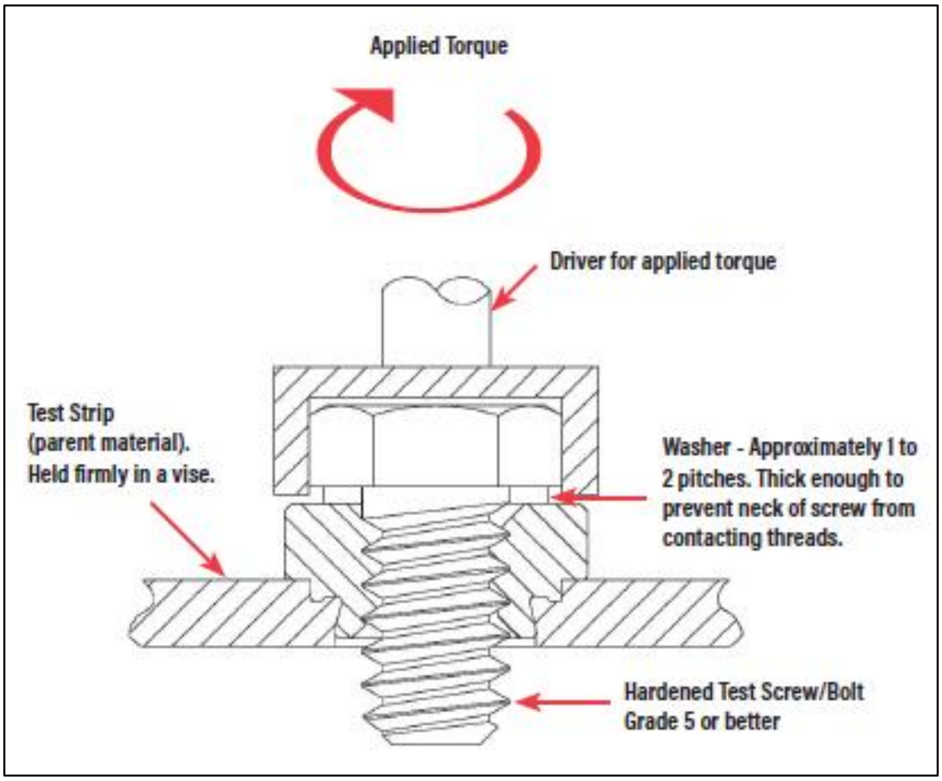

Figure 3.15: Self-clinching nut set-up for a torque-out test (PennEngineering, 2017).

3.9 Analysis Using Taguchi Method

The intention of the Taguchi method is to maximize the signal to noise ratio and to minimize the effect of random noise factors which have an impact on the performance of the testing (Dasgupta & Mukherjee, 2016). S/N ratio analysis was done with torque-out as the performance index and all the calculations were conducted in Minitab Software. As torque-out value is to be maximized, S/N ratio was calculated using HB (Higher the Better) criterion and was given by:

$$S/N = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

Where y is the observed data and n is the number of observation (Dasgupta & Mukherjee, 2016).

Table 3.2: Design factors and parameters

Design Factors	**Unit**	**Levels**				
		1	2	3	4	5
Materials type		Mild Steel	Aluminium 5052			
Thickness	**mm**	2.00	3.00			
Hole Diameter	**mm**	8.67	8.71	8.75	8.79	8.83

The design factors and its parameter for Taguchi analysis are given in Table 3.2. The analysis to determine the optimal parameters that are significant to the performance of self-clinching nut was conducted in three categories which are the first category involve only Mild Steel Host panel, the second category involve only Aluminium 5052 host panel and the third category involve analysis that combines both host panels.

For Mild Steel and Aluminium 5052 host panel analysis, thickness and hole diameter was selected as the factors and torque-out as the response data to analyse the Taguchi design while for combination (Mild Steel and Aluminium 5052) analysis, material type, thickness and hole diameter was used as the factors.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Overview

The highest torque values on the self-clinching nut's performance of each material type with a variety of holes diameters and thickness are obtained from the torque-out test and discussed in this chapter. By using the Taguchi method, the effect of hole diameter, sheet thickness and material types of the panels are analysed and discussed in this section. Hence, the level of importance for each testing parameter that affects the torque values are determined.

4.2 Results

4.2.1 Mild Steel Torque-out Test

Figure 4.1 shows the graph of torque values for Mild Steel host panel of 2 mm thickness and Figure 4.2 shows the graphs of torque values for Mild Steel host panel of 3 mm thickness. The graphs are generated from the data that are collected from PicoLog Recorder during the torque-out test. The coloured lines illustrate the variety of holes diameters that are used in the testing and the highest torque value for each diameter are labelled as shown in the figures.

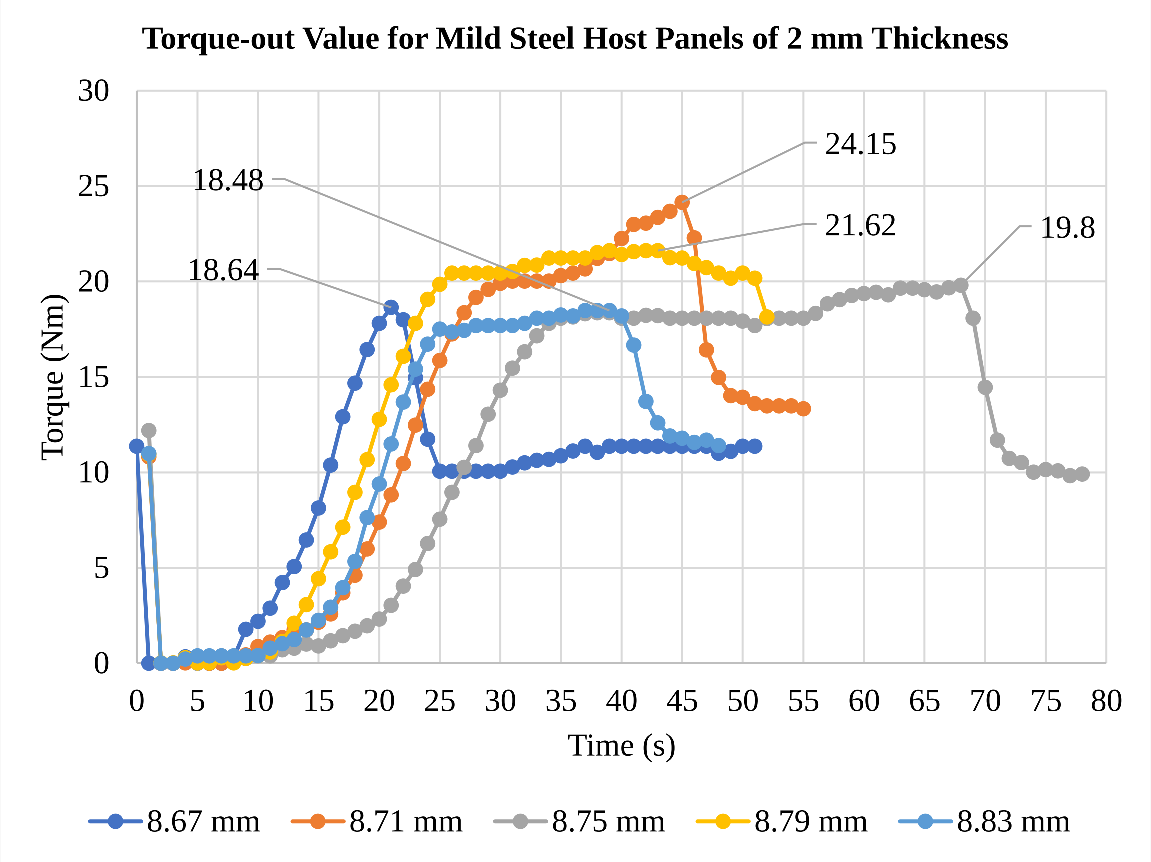

Figure 4.1: Torque values for Mild Steel host panels of 2 mm thickness

From Figure 4.1, the highest torque-out value to the performance of the self-clinching nut is on hole diameter of 8.71 mm with 24.15 Nm of torque value. The second highest torque-out value is on 8.79 mm followed by 8.75 mm, 8.67 mm, and 8.83 mm with a torque value of 21.62 Nm, 19.80 Nm, 18.64 Nm, and 18.48 Nm respectively.

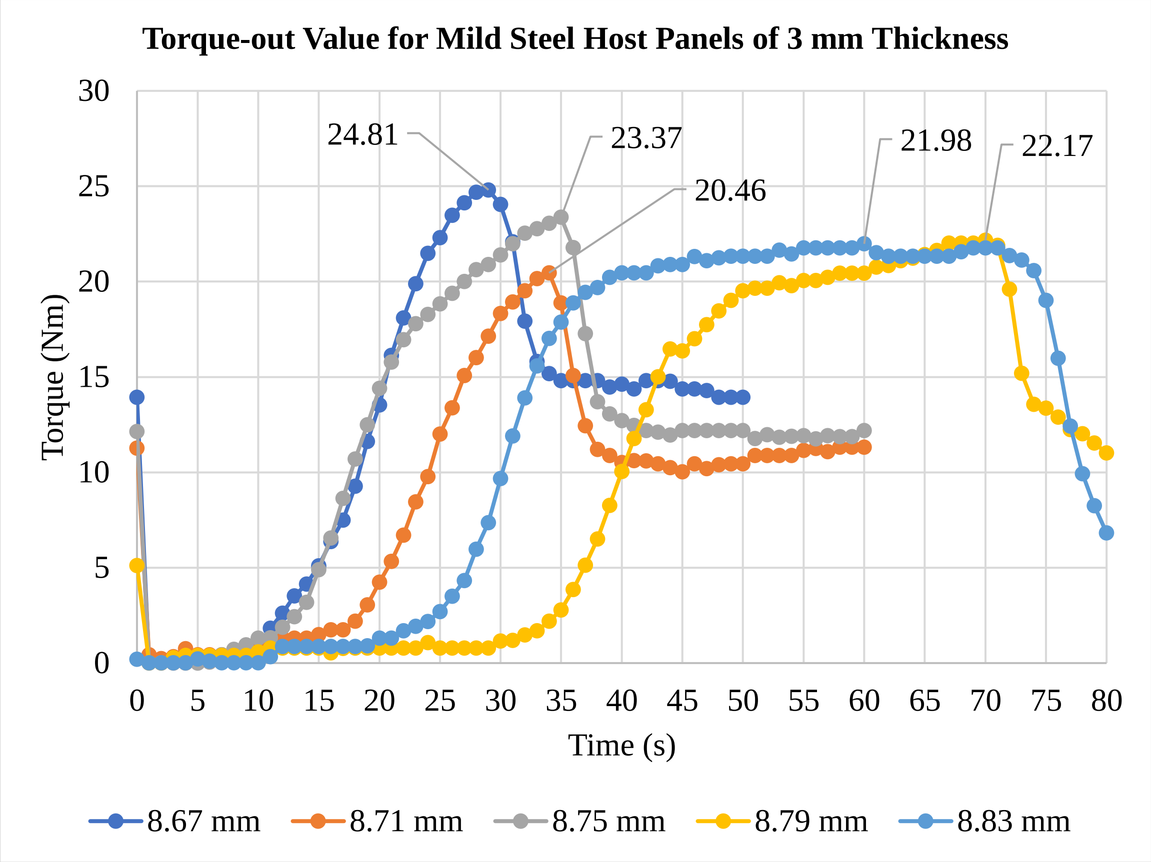

Figure 4.2: Torque values for Mild Steel host panels of 3 mm thickness

From Figure 4.2 for Mild Steel with 3 mm thickness, the highest torque-out value which the nut rotates within the host panel is on hole diameter of 8.67 mm with 24.81 Nm of torque value. The second highest torque-out value is on 8.75 mm followed by 8.79 mm, 8.83 mm, and 8.71 mm with the torque-out value of 23.37 Nm, 22.17 Nm, 21.98 Nm, and 20.46 Nm respectively.

Table 4.1: Torque-out value for Mild Steel host panel.

Materials Type	Thickness (mm)	Hole Diameter (mm)	Torque-out Value (Nm)
Mild Steel	2.00	8.67	18.64
Mild Steel	2.00	8.71	24.15
Mild Steel	2.00	8.75	19.80
Mild Steel	2.00	8.79	21.62
Mild Steel	2.00	8.83	18.48
Mild Steel	3.00	8.67	24.81
Mild Steel	3.00	8.71	20.46
Mild Steel	3.00	8.75	23.37
Mild Steel	3.00	8.79	22.17
Mild Steel	3.00	8.83	21.98

Table 4.1 shows the extracted toque-out value from Figure 4.1 and 4.2 for different holes diameter on the Mild Steel host panels. The table includes both 2 mm and 3 mm thickness of the panel and as shown in Table 4.1, Mild Steel host panel with 3 mm thickness and 8.67 mm hole diameter has the highest torque-out value which is 24.81 Nm among both 2 mm and 3 mm of the thickness.

4.2.2 Aluminium 5052 Torque-out Test

Figures below show graphs of torque values for Aluminium 5052 host panel of 2 mm (Figure 4.3) and 3 mm (Figure 4.4) thickness that are generated from the data recorded by PicoLog Recorder during the torque-out test. The coloured lines illustrate the variety of holes diameters that are used in the testing and the labelled value is the highest torque value for the specified hole diameter before the nut rotates within the holes.

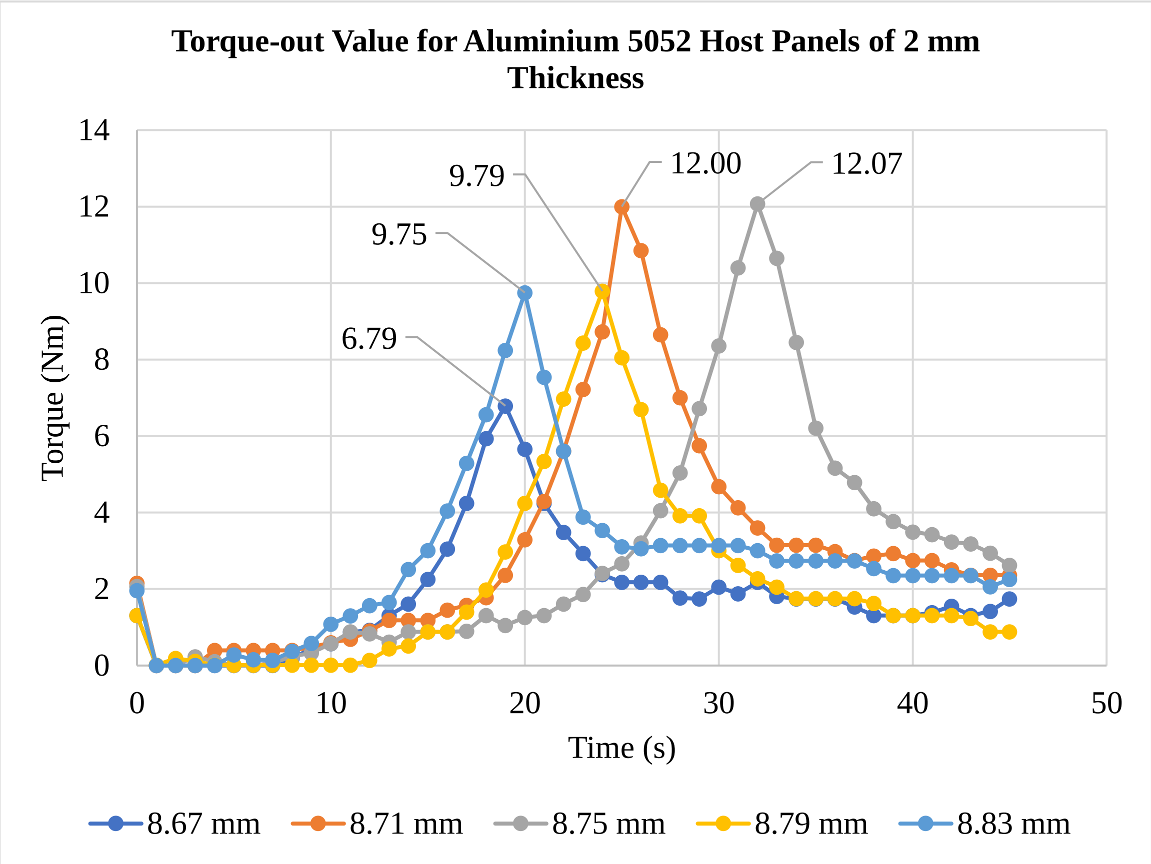

Figure 4.3: Torque values for Aluminium 5052 host panels of 2 mm thickness

Figure 4.3 illustrates that the hole diameter of 8.75 mm has the highest torque-out value of 12.07 Nm. The second highest is on the host panel with 8.71 mm diameter with a torque-out value of 12.00 Nm followed by diameter of 8.79 mm, 8.83 mm and 8.67 mm with the torque-out value of 9.79 Nm, 9.75 Nm, and 6.79 Nm respectively.