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Design and Analysis of Torque Handling Capacity of Slot Headed Grub Screw

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***Abstract*—The main objective is to optimization of strength of flat slotted screw head with different slot shapes. These slot shapes are modeled on Solid Edge ST2, mechanical design software and analyzed in ANSYS 14.5, a finite element analysis (FEA) software. The model consists of 3 slotted flat headed grub screw profile with their corresponding screw driver profile. The aim was to obtain the maximum torque handling capacity from among the identified slot shapes. For this purpose, an iterative process involving design up gradation and finite element analysis was done. To validate the model, testing was conducted on the specimen in the Torsion Testing Machine and results were compared. The study shows that a variation in the slot shape of a screw can influence the torque handling capacity Measurement of torque carrying capacity of flat headed screws by varying the slot angles and identify the one that withstands higher torque.**

The primary objective is to conduct torque test on screw specimen with different slot angles and to identify the slot shape angle that withstands higher torque, and to determine the variation of torque carrying capacity with slot angles, and to carry out Finite Element Analysis (FEA) and to compare the experimental results

The purpose of optimizing the slot shape design, an iterative process was carried on. Repetitive analysis on ANSYS® with a change in the design in SOLIDEDGE ST2 was conducted to make sure that failure occurs on the screw head. Methods followed to complete the tasks Identification of slot shape, Design of a grub screw, Holder and Driver Material Selection and properties, Fabrication of specimen, Experimentation conduct using Torsion Machine, Analysis using ANSYS workbench

***Index Terms*—**Grub screw, Finite Element Method, Torsion machine, Optimization, ANSYS.

I. Introduction

A screw is a type of fastener characterized by a helical ridge, known as an external thread or just thread, wrapped around a cylinder. The most common uses of screws are to hold objects together and to position objects. A screw will always have a head, which is a specially formed section on one end of the screw that allows it to be turned or driven. Common tools for driving screws include screwdrivers and wrenches. A variety of screw head shapes are available in the market, for example, slotted screw, hexagonal head cap screw, torx screw, slotted grub screw etc.

In order to drive a screw to hold objects together, its slotted head is turned by providing a moment by means of a screw driver. A variety of slot shapes with a flat head are available for this purpose. Out of which ‘slotted shape’ is commonly used. For a given slot shape configuration, the application of over-moment may result in a failure of the head.

When a moment is applied to a given slotted screw through a screw driver, it experiences normal and shear stresses. The interplay of these stresses gives an Equivalent (Von-Mises) stress. On varying the moment, the stress on the specimen increases, with a consequent failure of the head section. The failure may result due to normal stress or shear stress or most likely, interplay of both.

A need to optimize the shape of the slot arises for better moment transmission from screw driver to screw. For this, screw head specimens are prepared with a different slot angles and subjected to moment testing with their corresponding screw-driver profiles. The one with better moment carrying capacity is considered as optimum slot shape.

The majority of screws are tightened by clockwise rotation, which is termed a right-hand thread; a common mnemonic device for remembering this when working with screws or bolts is "righty-tightly, lefty-loosely." Screws with left-hand threads are used in exceptional cases.

A screw is an externally threaded fastener capable of being inserted into holes in assembled parts, of mating with a preformed internal thread or forming its own thread, and of being tightened or released by applying torque the head.

Grub screws are small headless (also called blind) screws having a slot cut for a screwdriver or a socket for a hexagon key and used to secure an object within or against another object. By being headless, it means that the screw is fully threaded and has no head projecting past the major diameter of screw thread. The most common examples are securing a pulley or gear to a shaft in a determined position. It exerts compression or clamping force through the bottom tip that projects through the hole. For the experiment, brass has been identified as the material for screw specimens. An example application is when a set screw is screwed into a pulley hub so that its end-point bears firmly against the shaft. The fastening action is by friction between the screw and the shaft, often (but not always) with some amount of elastic or plastic deformation of one or both.

Figure1.Commercially available Grub screws

Different types of Grub screws are Flat Point, Domed Point, and Cone Point, Cup Point, Knurled Cup Point, Dog Point.

II. IDENTIFICATION AND DESIGN OF GRUB SCREW FOR DIFFERENT SLOT SHAPE

The purpose of comparison of applied torque on various specimens, the area of contact between the screw head and driver is made constant for all pairs.

From the BIS standards of Grub screws*, M20 screw specification is selected considering practical feasibility of the project.

M20 flat headed slotted screw a have a depth, of 5mm and a width of as per the BIS standards. Taking the 0 flat head slotted screw as, the reference,3 profiles of screw-screw drive, pair was made, keeping the arc of contact constant namely, 0°, 17°, 34°. The 34° is the limiting case for the width of 3mm.

A Specimen

On identification of the slot angles, the design of the screws was finalized based upon the standard dimensions mentioned in Indian standard specifications for grub screws. After the finalization of screw designs brass was selected as the material based upon its applicability as a fastener in the market.

B Screwdriver

The purpose of transmitting torsional force from the twisting head of the torsion testing machine to the weight head, screwdriver profiles for the corresponding screws were identified. The design of the profile was done keeping in mind the dimensions required to insert it into the chuck of the twisting head of the torsion testing machine. We have chosen EN 19 alloy steel as the material for the driver profile. This material has been chosen to avoid failure of screwdriver during testing.

C Holder

The torsion testing of the slotted screw head required a special arrangement involving the holder-screw-driver assembly. The challenge for working in the torsion testing machine was to hold the screw head in the weight head chuck which had a specific design. To meet the requirement, specimen holder was designed to snugly fit inside the weight chuck with the screw head protruding from the opposite face. For this purpose, mild steel was chosen as the material for machining.

D. Indian Standard specification for slotted grub screws [Ref: Doc: EDC 27 (1662)]

Slotted grub screws are available in the size range of Ml to M24 and in different materials such as steel, brass, etc. 6 different shapes at the end of the screw are available, namely flat end (A), conical end(C), cylindrical dog point (E), tapered dog point (G), cup point (J) and oval point (K). The Dimensions for M20 grub screw are given in Fig2.2 and Table 2.1 below.

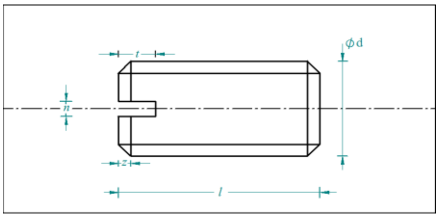

Figure 2. Indian standard dimension

Where, *l*= length of the screw,
t=Depth of the screw,
d=diameter of the screw,
n=width of the screw

TABLE I.
DIMENSIONS FOR M20 SCREW

	SIZE (DIAMETER)	M8	M10	M12	M14	M16	M18	M20	M22	M24
WIDTH OF SLOT	NOMINAL MAX MIN	1.2 1.45 1.20	1.6 1.85 1.60	2.0 2.25 2.00	2.0 2.25 2.00	2.5 2.75 2.50	3.0 3.25 3.00	3.0 3.25 3.00	4.0 4.30 4.00	4.0 4.30 4.00
DEPTH OF THE SLOT	NOMINAL MAX MIN	2.5 2.70 2.30	3.0 3.20 2.80	4.0 4.24 3.76	4.0 4.24 3.76	4.5 4.74 4.26	5.0 5.24 4.76	5.0 5.24 4.76	6.0 6.24 5.76	6.0 6.24 5.76

E Computer Aided Designing

SOLIDEDGE ST2 reduces the designing time and the Machining time. To get an accurate information, the user can display the in-process stock on each milling or turning operations. 2-D drafting and 3-D designing becomes very simplified with this software.

F Design

On identification of the slot angles, the design of the screws was finalized based upon the standard dimensions mentioned in Indian standard specifications for grub screws (2) [Ref: Doc: EDC 27 (1662)]. After the finalization of screw designs brass was selected as the material based upon its applicability as a fastener in the market.

A holder profile was required for holding the brass specimen while conducting the torsion test. For this purpose, the brass specimen should snugly fit inside the holder. Based upon a survey in market, hexagonal brass bar of (22mm opposite edge length) was chosen for making the screw specimens. Subsequently, a holder profile with a hexagonal pocket of 5mm depth was designed.

For the purpose of slot cutting the angular slot of 17° and 34° in the brass specimens, a single point HSS tool was designed.

The screwdriver profile for each of the screws was designed with appropriate tip angles. The design of the screwdriver and holder were in accordance with the shape of chuck on the Torsion Testing Machine.

The final design of various specimens is arrived after a number of iterations. The draft of these design of these designs are follows:

a) 2-D sketch of specimens with different slot angle

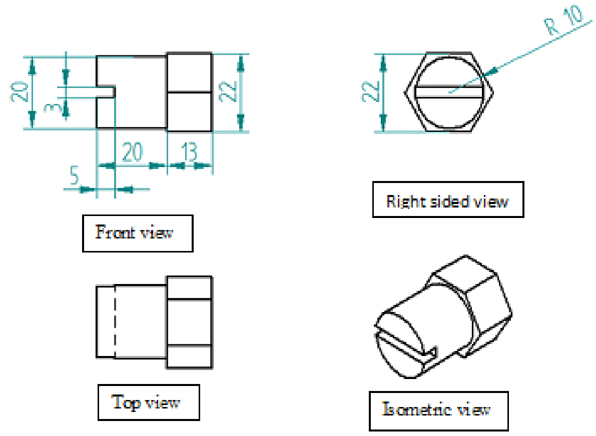

Figure 3: Sketch of 0° screw specimen

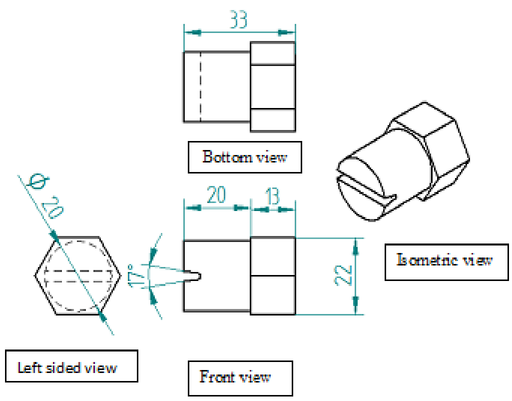

Figure 4. Draft of 17° screw specimen

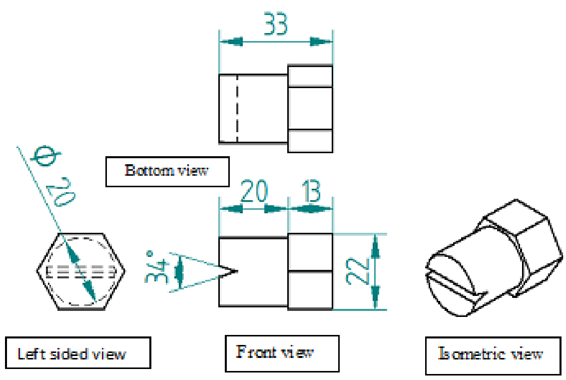

Figure 5. Draft of 34° screw specimen

b) 2-D sketch of specimens with different tip angle

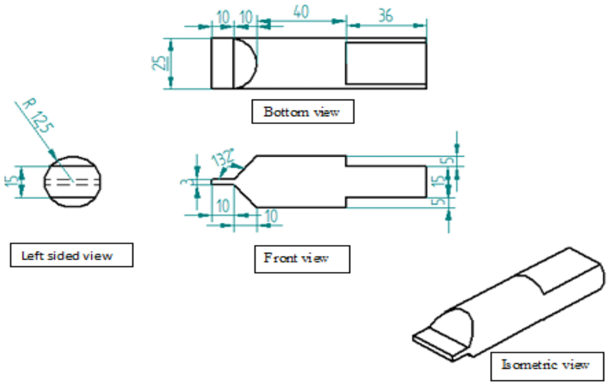

Figure 6. Sketch of 0° driver

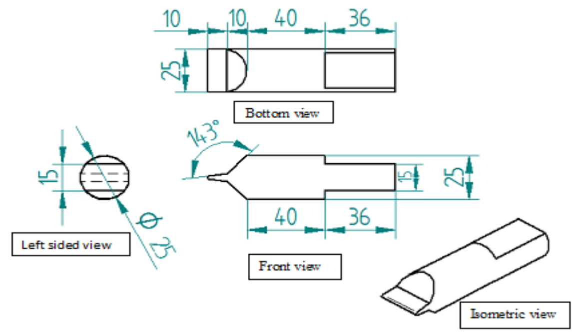

Figure 7. Sketch of 17° driver

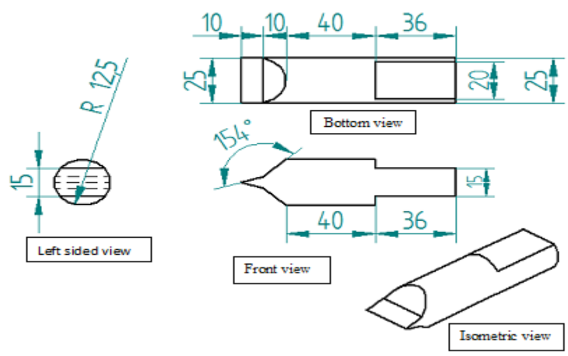

Figure 8. Sketch of 34° driver

c) 2-D sketch of holder

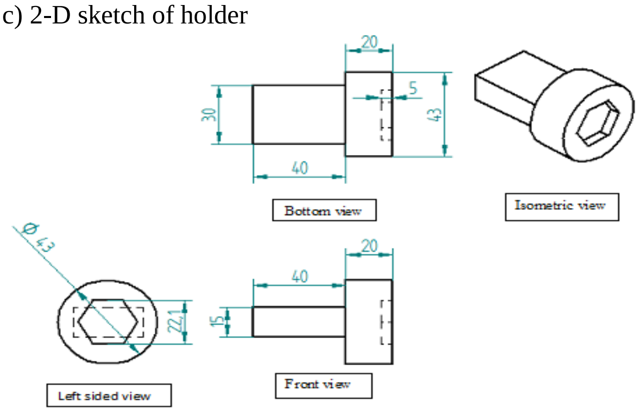

Figure 9.Sketch of holder

III. FABRICATION OF SPECIMEN, DRIVER AND

HOLDER

A Fabrication of specimen

The machine used to fabricate the specimen is Agni Fritz Werner Ltd make, C.N.C machine

A shaper tool of HSS (S-500) grade was used for making the angular slots of 17 & 34 on the brass specimen. The tool specifications are as follows.

3/8" square * 4"long.Face angle of 17 and 34 on the two ends a positive back rake angle of 2 deg. side clearance angle of 6 deg.a nose radius of 0.2 mm. front clearance (for single point cutting tool) as 6°.

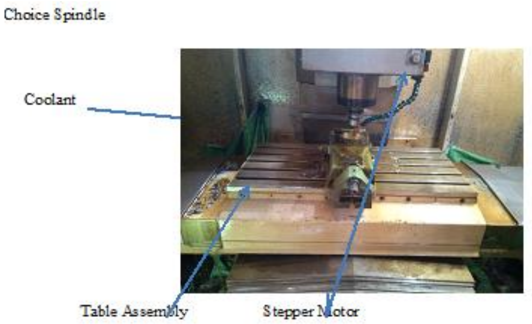

Figure 10. Operations performed on CNC machine

The hexagonal brass rod was turned on lathe to make the diameter as 20mm on one end. After this, the slot shape was made using shaper machine and grinding was done to obtain edge fillet.

Figure 11: 0° Specimen, 170 Specimen, 340 Specimen

For this purpose of machining if holder profile, a 45mm mild steel rod was chosen and turned to 43 mm on one end and 30 mm on other end. This was followed by shaping the standard holding dimensions for the chuck. Subsequently, a hexagonal pocket at the centre was machined in vertical CNC in order to snugly fit the hexagonal brass bar.

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Figur12: Holder

The EN 19 Alloy Steel was turned on lathe to obtain a diameter of 16 mm on one end and 25 mm 25 mm on the other end. This was followed by shaping the standard holding dimension for the chuck. Further machining of the tip was done on 4 axis CNC lathe.

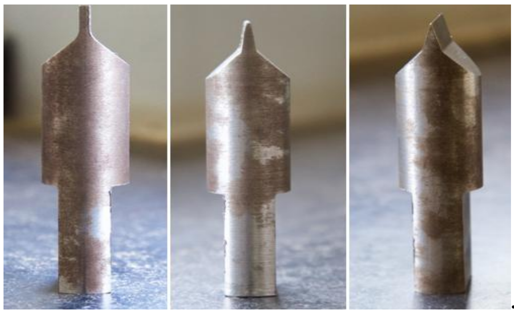

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Figure 13: 0° Driver, 170 Driver, 340 Driver

IV. EXPERIMENTATION TO FIND THE MAXIMUM TORQUE CARRYING CAPACITY OF SLOTTED GRUB SCREW

A Torsion Testing Machine

Torsion testing machine is machine which is used to test the torsional moment by applying the twisting force to the body.

Torsion-testing equipment consists of a twisting head, with a chuck for gripping the specimen and for applying the twisting moment to the specimen and a weight head, which grips the other end of the specimen and measures the twisting moment of torque.

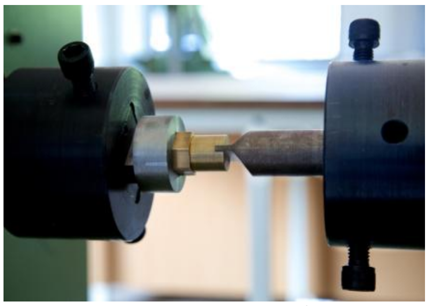


Figure14: Experimental Setup for 0° Specimen

TABLE II:
EXPERIMENTAL RESULT OF SPECIMEN WITH 0° SLOT ANGLE

Θ- Angle of twist in degrees	Torque in Kg-cm Specimen 1	Torque in N-m Specimen 1	Torque in Kg-cm Specimen2	Torque in N-m Specimen 2
0.5	40	3.94	60	5.886
1.0	100	9.81	110	10.791
1.5	200	19.62	220	21.582
2.0	280	27.468	280	27.468
2.5	380	37.278	360	35.316
3.0	480	47.088	470	46.107
3.5	560	54.936	580	56.898
4.0	640	62.784	640	62.784
4.5	710	69.651	720	70.632
5.0	790	77.499	780	76.518
5.5	800	78.48	810	79.461
6.0	860	84.366	840	82.404
6.5	900	88.29	900	88.29
7.0	940	92.214	950	93.195
7.5	1000	98.1	990	97.119
8.0	1020	100.062	1020	100.062

TABLE III:
EXPERIMENTAL RESULT OF SPECIMEN WITH 17° SLOT ANGLE

Θ- Angle of twist in degrees	Torque in Kg-cm Specimen 1	Torque in N-m Specimen 1	Torque in Kg-cm Specimen 2	Torque in N-m Specimen2
0	0	0	0	0
0.5	60	5.886	40	3.924
1.0	180	17.658	120	11.772
1.5	310	30.411	210	20.601
2.0	450	44.145	300	29.43
2.5	600	58.86	410	40.221
3.0	760	74.556	620	60.822
3.5	930	91.233	780	76.518
4.0	1060	103.986	900	88.29
4.5	1170	114.777	980	96.138
5.0	1260	123.606	1160	113.796
5.5	1350	132.435	1220	119.682
6.0	1430	140.283	1310	128.511
6.5	1500	147.15	1390	136.359
7.0	1560	153.036	1460	143.226
7.5	1630	159.903	1530	150.093
8.0	1670	163.827	1570	154.017
8.5	1700	166.77	1620	158.922
9.0	1720	168.732	1660	162.846
9.5	1735	170.20	1680	164.808
10.0	1745	171.1845	1690	165.789
11	1755	172.1655	1700	166.77

TABLE IV:
EXPERIMENTAL RESULT OF SPECIMEN WITH 34° SLOT ANGLE

Θ- Angle of twist in degrees	Torque in Kg-cm	Torque in N-m	Torque in Kg-cm	Torque in N-m
0.5	60	5.886	50	4.905
1.0	90	8.829	80	7.848
1.5	140	13.734	150	14.715
2.0	190	18.639	180	17.658
2.5	220	21.582	190	18.639
3.0	240	23.544	200	19.62
4.0	245	24.0345	270	26.487
5.0	Slippage occurred	Slippage occurred	Slippage occurred	Slippage occurred

The data obtained in above table I to IV are based upon gradual increase in the Torque testing machine and values of torque were recorded on the Kg-cm scale. While applying the torque, the screw specimens were carefully observed for any deformations or cracks near the slot as inferred from the ANSYS results.

B Analysis Using Ansys Workbench

Various parts were assembled in SOLID EDGE ST2.These assembled models are then transformed into IGES files (Initials Graphic Exchange Specifications) which are common file format for interactions of any CAD software with ANSYS. An iterative process was followed which involved over 50 iterations in order to arrive at final design of the screw-screw driver assembly. These iterations were carried out after incorporating the material properties of Brass, Alloy Steel (EN19) and Mild Steel. A single iteration involved testing of particular assembly design at various torque till the point of failure was observed on the screw specimen.

The ANSYS workbench interface has a number of analysis System, out of which, static structural system was most appropriate for our model.

Once inside the static structural system following steps are followed.

1) Engineering data involving all the material properties are entered. For the given model involving Brass, EN 19/AISI 4140 Alloy Steel and Mild Steel, properties such as Density, Young's Modulus, Poisson's Ratio, Tensile Yield Strength, Tensile Ultimate Strength were required. These were entered in property table.
2) The next step involves importing the geometry file. The SOLID EDGE files after conversion into IGES format are imported for use in the downstream operations.
3) The imported geometry is then updated and the design modeller is opened. Once inside the Design modeller, each part of the assembly is given its respective property. For instance, Holder is assigned as Mild Steel, Screw is assigned as Brass and Screw Driver is assigned as Alloy Steel.
4) Contact regions are defined and connections are made.

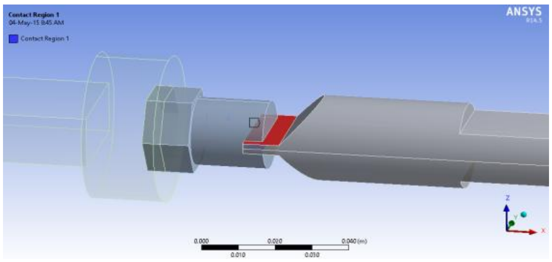
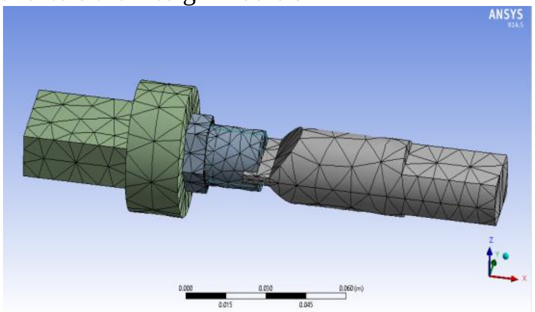


Figure15. Figure showing contact regions

5) Meshing of model is done next. In the work bench automatic meshing is done by the software once the model enters the Design Modler.



Figur16. Figure showing meshing in design Modeller

6) The model enters the static structural mode where initial conditions, loads and supports are defined. The holder is given a fixed support and moments given to the screw driver. The screw driver being snugly fit inside the holder is constrained from rotation about its axis.
7) Inside the static structural analysis, the ANSYS workbench provides the user with variety of solutions. These include deformations, strain, stress, energy, etc. In this project analysis include solutions for Shear Stress, Normal Stress, Equivalent Stress, Maximum Shear Stress, and Total Deformation.
8) The results are then obtained once all the required upstream data is available

The ANSYS Workbench platform is the framework upon which the industry's broadcast and deepest suite of advanced engineering simulation technology is built. An innovative project schematic view ties together the entire simulation process, guiding the user through even complex multi-physics analysis with drag-and-drop simplicity. With the bidirectional CAD connectivity, powerful highly-automated meshing, a project-level update mechanism, pervasive parameter management and integrated optimization tools, the ANSYS Workbench platform delivers unprecedented productivity, enabling Simulation-Driven Product Development.

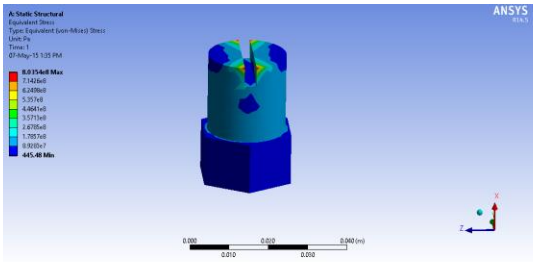


Figure17.Equivalent Stress on 00 Screw specimen

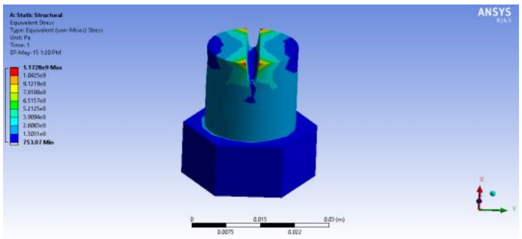


Figure18.Equivalent Stress on 17° Screw specimen

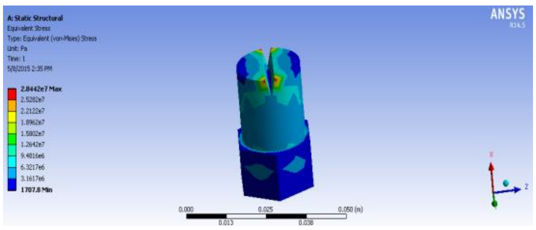


Figure19. Equivalent Stress on 34° Screw specimen

V. RESULTS AND DISCUSSIONS

Based on the data recorded, graphs have been plotted with Moment of force(N-m) on Y-axis and angle of rotation(degrees) on X-axis.as shown in Figure19 to Figure22.

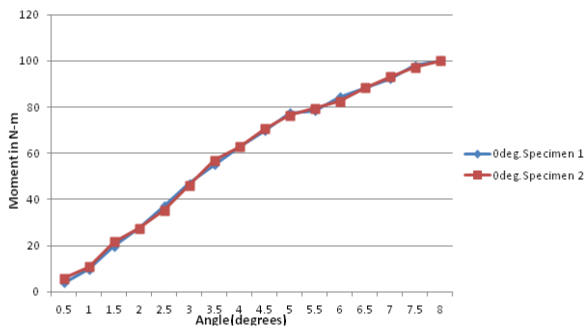


Figure 20. Experimental data for 0° Slot angle Specimen

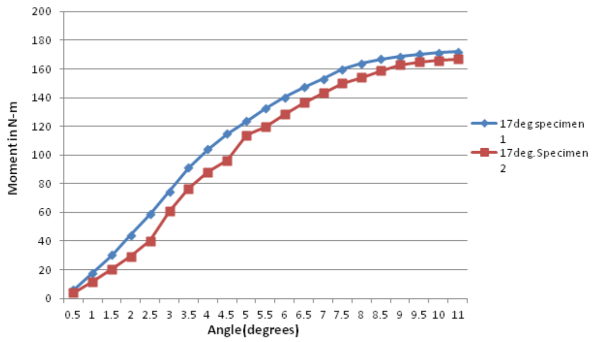


Figure 21: data for 17° Slot angle Specimen

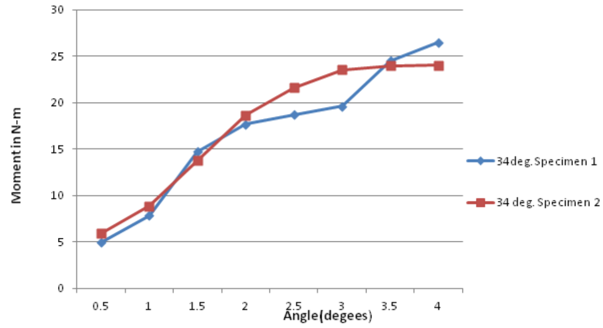


Figure 22. Graph of data for 34° Slot angle Specimen

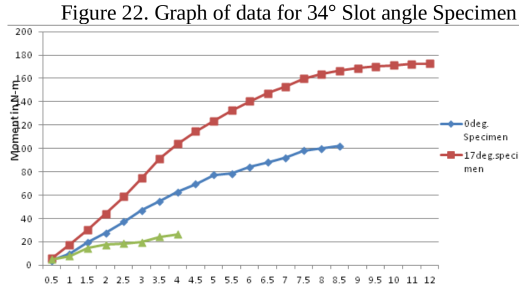


Figure 23: Comparison of experimental data for all 3 types of Specimen

Analysis is carried on ANSYS fetched a lot of data regarding the stress concentration on the screw-screwdriver profile which gave an estimate of failure. For this purpose, Equivalent Stress (Von-Mises) was taken into consideration since the stresses acting on the specimens are not purely Normal or Shear in Nature, but a combination of two. Thus, on increasing the moment, the stresses on the specimen increases which, consequently gives the failure torque.

TABLE 5:
EQUIVALENT STRESS (VON-MISES)

Sl.No	Type of Specimen	Experimental Torque (N-m)	Max. Equivalent Stress Obtained analytically (N/m^2)
1	0^0 Screw Specimen	100.062	8.0354e8
2	17^0Screw Specimen	172.1655	1.1728e9
3	34^0 Screw Specimen	26.487	2.8442e7

IV. CONCLUSIONS

The torque carrying capacity of the grub screw with slot angle of 17° is found to be higher than 0° slot angle.The torque carrying capacity of the grub screw with slot angle 17°is found to be 1.72 times more that of 0° slot angle.The maximum torque carrying capacity of the grub screw with slot angle 34° could not be evaluated since the screw and screw driver pair underwent slip at 4° of rotation at an applied torque of 26.487N-m because of non- supportive grip angle. Hence this Slot shape for a screw is not recommendable as slipping will occur while tightening for an insufficient screw driver axial force.From the FEM analysis it is been noted that Equivalent stress of 17°Slot angle is 1.45 times that of screw with 0° slot angle.

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