Failure Analysis of Tractor Steering Column and Worm Stem Weld

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***Abstract*—This paper deals with failure analysis of steering column and worm stem welding(friction weld), which may get fail due to fluctuating forces during bumping of vehicle due to which shock will be generated in the suspension as well as steering system. While manufacturing the steering column and worm stem components, we have to consider some of the factors like case hardening and welding which may lead to failure. A small voids or internal crack in the weld joint cause failure in the joints. The objective of this research is to determine the strength at joints, hardness and mechanical properties. The Vickers hardness test is conducted to determine the hardness at the weld joint and also worm stem and steering column area. For the mechanical properties, tensile strength, bending strength and torsion shear stress are found experimentally, theoretically and also in FEA solutions.**

Key Words: **Friction weld, Torsion shear stress, Vickers hardness, Bending strength, tensile strength and FEA**

I. Introduction

1 Introduction to Fracture

This section portrays the significant reasons for mechanical fracture of the designing parts or structure. Different level of materials execution is presented. Damage of structure because of the break, exhaustion, creep; wear and consumption have been disclosed to comprehend the regular mechanical fracture. [10]

Despite the fact that the reasons for disappointment are known, counteractive action of fracture is hard to ensure. Reasons for damage of structure include: ill-advised materials determination, dishonorable preparing, lacking configuration, abuse of a segment, and inappropriate upkeep. It's the specialist's obligation to envision and get ready for conceivable damage. To evaluate its cause and after that consider proper measures. [11]

Basic components or any machine components can neglect to perform their expected capacities in three general ways: extreme versatile distortion, over the top plastic twisting or yielding, and crack. The class of damage because of extreme versatile disfigurement, for instance: excessively adaptable any types of shaft can bring about quick wear on the bearing parts. Then again sudden clasping sort of damage may happen. Fracture because of intemperate flexible miss happening is controlled by the different types of flexible elements, other than the quality material.

Designing materials does not achieve hypothetical quality when they are tried in the research facility. In this way, the execution of the material in administration is not same as it is normal from the material; subsequently, the configuration of a segment much of the time entreats the designer to decrease the likelihood of fracture. In any case, the level of execution of segments in administration relies on upon a few elements, for example, intrinsic properties of materials, load or stretch framework, environment and support.

The standard reasons for mechanical fracture in the segment or framework are:

- Blunders in assembly
- Manufacturing imperfections
- Improper or lacking support
- Design errors/ blunders or plan insufficiencies
- Failure by crack because of static over-load.
- Buckling in segments because of compressive overload

The outline of a part or structure regularly solicits to minimize the likelihood from disappointment. The disappointment of metals is a mind boggling subject which must be managed break or other applicable wonder. In this way, it is vital to comprehend the diverse sorts of mechanical disappointment i.e. brake, exhaustion, creep, consumption, wear and so on.

2 Introduction of Manual Steering Mechanism

The system, administering the precise development of front wheels of a tractor is called guiding steering system. This system minimizes the endeavors of the operator or driver in turning the front wheels with the utilization of influences. Fig 1 demonstrates the distinctive segments of directing steering system are i) steering wheel ii) guiding shaft iii)steering gear iv) drag join v)steering arm vi) drop arm When the operator turns the controlling wheel, the movement is transmitted through the directing shaft to the angular movement of the pitman arm through an arrangement of gears. The precise development of the pitman arm is further transmitted to the guiding arm through drag connection and tie bars. Guiding arm is keyed to the separate kingpins, which are indispensable part of the stub pivot on which wheels are mounted. The development of directing arm influences the development of front wheel.

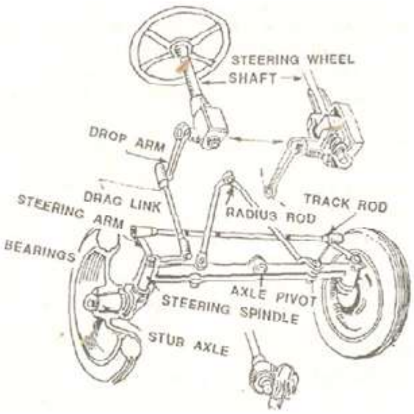

Fig 1 Steering Mechanism

3 Introductions to Case Hardening Process

[12] Case hardening is a process of increase hardness of the metal surface is fortified by the including of a thin layer at the highest point of another metal amalgam that is for the most part more strong. Case solidifying steel is regularly used to expand the component life. This is especially huge for the assembling of mechanical components, different equipments. Case solidifying is likewise used for different occasions. Case solidifying is additionally called surface solidifying.

3.1 Carburizing

The carburizing process is to give a hard surface on typically un hard empower steels materials also we can use this to other materials. Here the strategy for a steel material that is low carbon steel which having typically 0.20 percent carbon and lower is set in an environment that have a considerable measure of carbon monoxide.

The carburizing furnace temperature is 930°C At the time of process this temperature the greatest measure of carbon then it is can be broken up in austenite can be discovered from line of the iron-iron carbide balance graph. In this way, rapidly, a surface thickness of layers of high carbon is developed in the stage. And the surface is hardened by addition of containing of heat. The core of material is constant when we cut that material by section we can see the hardness layers are coming out of the circling of the shaft. Commercial carburizing might be completed by a method for pack carburizing, gas carburizing and liquid carburizing.

4 Introductions to Friction Welding

Linear Friction Welding:

Butt Welding Linear Friction Welding (LFW) empowers the joining of hard to bond materials can be utilized as a repair procedure, and to manufacture the intricate structures. Basically, it is a non-melting combination process delivering high honesty welds with minimal earlier surface arrangement required. Straight grating welding, (so named on the grounds that the relative movement is direct over the interface, as opposed to rotating). Lower cost straight grating welding machines are presently being produced for automotive applications, for example, the manufacture of brake plates, wheel rims and motor parts. As the parts to be welded are constrained into intimate contact, a completely turned around movement is forced on part of the framework. This produces frictional heat in the prompt district about the weld plane, in this manner softening a finite volume of material. As the weld continues, a segment of this visco-plastic layer is expelled at the periphery of the weld interface, in undulated sheets of metal known as glimmer. This ought to guarantee that any interface contaminant is removed. The blend of quick joining times on the request of a few moments, and the immediate heat contribution at the weld interface, offers ascend to moderately little heat affected zones. This, by sensible determination of segment geometry, this likewise restrains process actuated contortions.

4.1 Heat Affected Zone (HAZ)

For any welding procedure that utilizes heat to acquire coherence between the particles, particles, or atoms of adjoining work pieces, there can be an impact on the microstructure and properties, regardless of the fact that there is no dissolving of the base materials. When the welding is done the heat of the material increase and heat affected zone (HAZ) is also increase. Then the heat influenced zone is by increase of welding temperature and HAZ is very important fact in material for finding strength of the material. At the point of welding of the material the distance between two sides of weld is very important fact for heat affected zone. As the distance travelled the effect will reduce. The affected zone is measured by the Vickers hardness test. Fig 2 shows the Heat Affected Zone (HAZ)

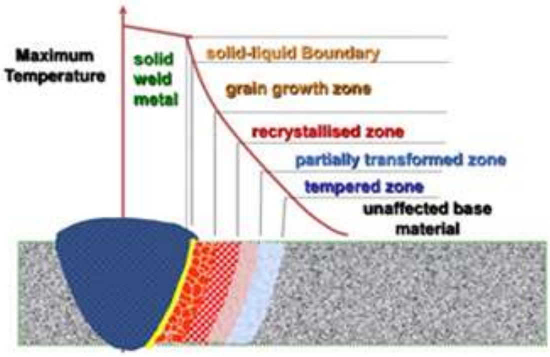

Fig 2 Heat Affected Zone (HAZ)

II WORK METHODOLOGY

In this study, we conducted the analysis of steering column and worm stem weld by subjecting it to tensile and bending forces and also analyzing by FEA and theoretical calculation. In this study we prepared 3 different types of specimen bases on various friction pressure and friction time then experiment was conducted to find the reasons of failure of weld. In this study maximum tensile stress and bending stress are considered for evaluating the experiment and FEA results.

1 High Strength Chromium Molybdenum Steel (SCM 420)

SCM420 works in the non-corrosive temperature below 250 ℃ and working. It is good in weld ability. Machinability and cold straining plasticity is good and high pressure pipe etc. It is high strength Chromium Molybdenum Steel. It's a JIS Standard. It equivalent to AISI 4130 OR SAE 4130.table 1 shows the chemical composition of material respectively.

Table 1 Chemical Composition of SCM 420

Elements	**Symbols**	**Values in percentage**
Carbon	C	O.18 – 0.23
Manganese	Mn	0.60-0.90
Silicon	Si	0.15-0.35
Nickel	Ni	0.25
Molybdenum	Mo	0.15-0.25
Chromium	Cr	0.90-1.20
Copper	Cu	0.30
Sulfur	S	0.030
Phosphorous	P	0.030

2 Unalloyed Medium Carbon Steel (EN 8)

This material is medium ,carbon steel usually supplied in untreated form. It has good tensile strength and is often used in application of: shafts, bolts, keys, gears, stressed pins, studs, etc. It is a very popular grade and machinable in any condition. It can be further surface-hardened to produce parts or segments with enhanced wear resistance. Therefore EN8 of larger sizes are recommended table 2 shows the chemical composition of materials, respectively.

Table 2 Chemical Composition of EN 8

Elements	**Symbols**	**Values in percentage**
Carbon	C	O.36– 0.44
Manganese	Mn	0.60-1.0
Silicon	Si	0.10-0.40
Sulphur	S	0.050
Phosphorous	P	0.050

3 Theoretical Expressions

Theoretically it's very important to get the solution for comparing with the experimental values so below equations are used to find tensile, bending and torsion stress.

Tensile Stress:

$$\sigma = \frac{P}{A} \text{ N/mm}^2$$

Bending Stress:

$$\sigma_b = \frac{PL}{Z} \text{ N/mm}^2$$

$$\Delta = \frac{PL^3}{48EI} \text{ mm}^2$$

Shear Stress in Torsion:

$$\tau = \frac{\pi d^3 T}{16} \text{ N/mm}^2$$

P = Applied Load
L= Length of Shaft
d = diameter of shaft

$$A = \frac{\pi d^2}{4} \text{ mm}^2$$

$$I = 0.78r^4$$

$$z = 0.78r^3$$

4 Experiment Details

Experiment is carried out in Rane (Madras) Limited, Mysore (RML). To find the strength of the welded joint, various experiments have been conducted like, tensile test, 30^0 bending test until fracture in a universal testing machine and Vickers hardness test to find the failure amylases of steering column.

Tensile Test

Tensile tests were carried out after welding was performed, tensile test specimen was machined in a lath machine with the standards of ASTM the dimensions of test specimen as per given in fig 3 Test specimen diameter 10mm and gauge length of 60mm. Welding place is comes middle of the gauge length so we can get accurate strength of the weld. The test specimen is carried on universal testing machine of capacity 100 KN and temperature will be ambient temperature, then the test is carried for 3 trials with based on different friction pressure then the welding strength will get by test this specimen. The test specimen is carried till its failure or crack occurs and the value of this maximum load is tabulated then divided by the area of cross section of the material. And compare these results with theoretical values . And the tensile test strength should be 325 MPa according to the company aspect for safe design

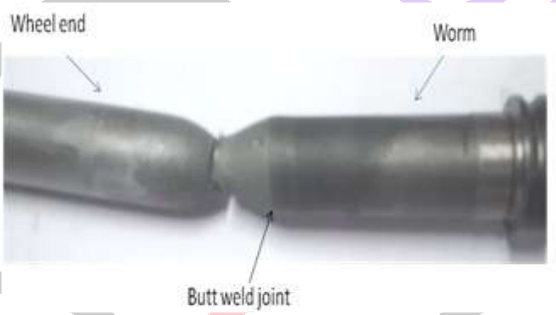

Fig 3 Steering Column Tensile Test Specimen

30^0 bending test

30^0 bending test is conducted to find the bending strength and deformation of joints under constant load condition (40kN) as shown in fig 4. And also to find the fracture strength of the weld area. It is a distraction test which gives full details of the failure zone of welding. We can observe cracks occurred after bending in fig 4 The Crack will occur on weld joint.

Fig 4 30^0 Bending Test.

Vickers Micro hardness test

The hardness variation within the heat affected zone (HAZ), influence the Strength of joints. Under 500 g loads, hardness variation was obtained by micro hardness using a digital micro hardness test machine and measuring locations. They are shown in Fig.5 the test was conducted at the point of the weld and in the regions near both the Steering column side and the worm stem side. Hardness varies horizontally on the both sides of the weld interface.

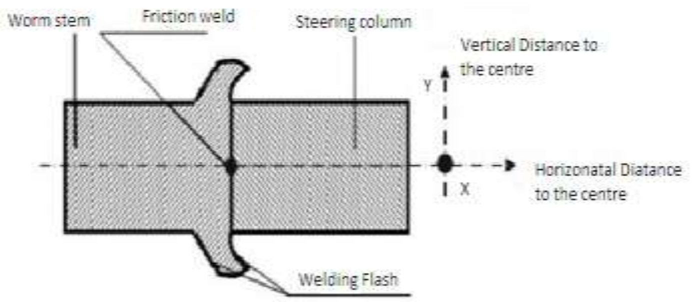

Fig.5 Hardness Test Orientation

III RESULTS AND DISCUSSION

The present investigation includes calculated records consisting of theoretical, experimental and FEA results and also related tables and graphs.

1 Theoretical Calculation

Tensile Stress

P = 65kN

d = 16 mm

$$\mathbf{A = \frac{\pi d^2}{4}}$$

$$\mathbf{A = \frac{\pi 16}{4}}$$

$$\mathbf{A = 201.08\ mm^2}$$

$$\boldsymbol{\sigma} = \frac{\mathbf{65000}}{\mathbf{201.08}}$$

$$\boldsymbol{\sigma} = \mathbf{323.38\ N/mm^2}$$

Bending Stress and Deformation

P= 40kN

L=160mm

E=200000MPa

r = 10 mm (radius of the shaft)

$$z = 0.78r^3 \quad = 6240\ mm^3$$

$$I = 0.78r^4 \quad = 124800\ mm^4$$

$$\sigma_b = \frac{PL}{z} = \mathbf{256.41\ N/mm^2}$$

$$\Delta = \frac{PL^3}{48EI} = \mathbf{0.136\ mm}$$

Shear Stress in Torsion

T= 100N.m

d=20mm

$$\tau = \frac{\pi d^3 T}{16} = \mathbf{15.71\ N/mm^2}$$

2 Experimental Result

Tensile Strength Result:

Table 3 Tensile Test Results

Trial No	Friction Pressure (Mpa)	Friction Time (Sec)	Load(kN)	Tensile Strength (Mpa)
1	88	10	54.2	269.15
2	145	8	59.3	295.02
3	198	6	64.8	322.38

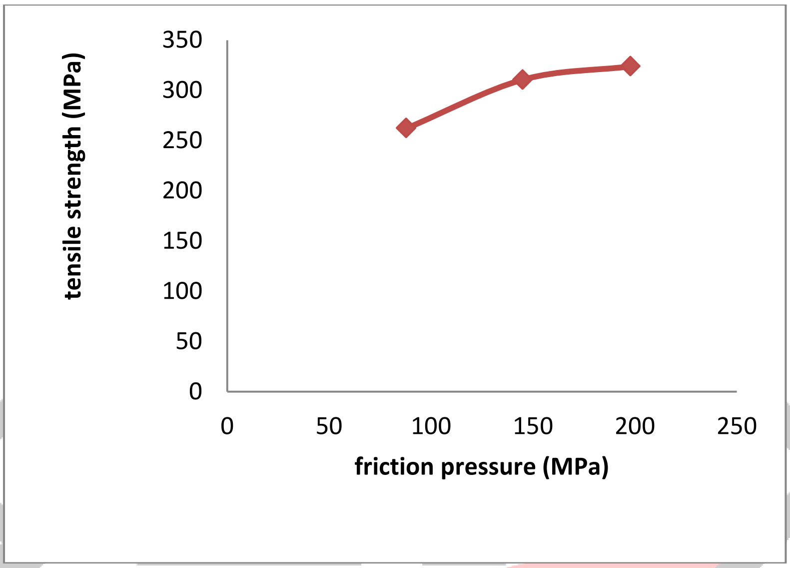

Fig 6 Relation between Tensile Strength and Friction Pressure.

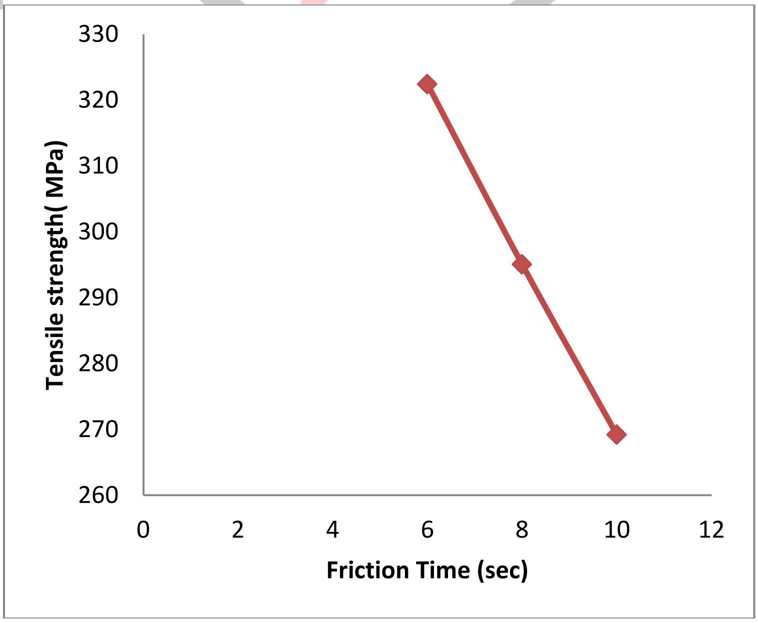

Fig 7 Relation between Tensile Strength and Friction Time.

30^0Bending Test Result:

Table 4 30^0 Bending Test Results

Sl.No	Pressure (Mpa)	Friction Time (Sec)	Load(Kn)	Deformation(Mm)	Remarks
1	91	9	40	3.63	Crack in weld
2	141	8	40	2.41	No crack
3	201	5	40	1.43	No Crack

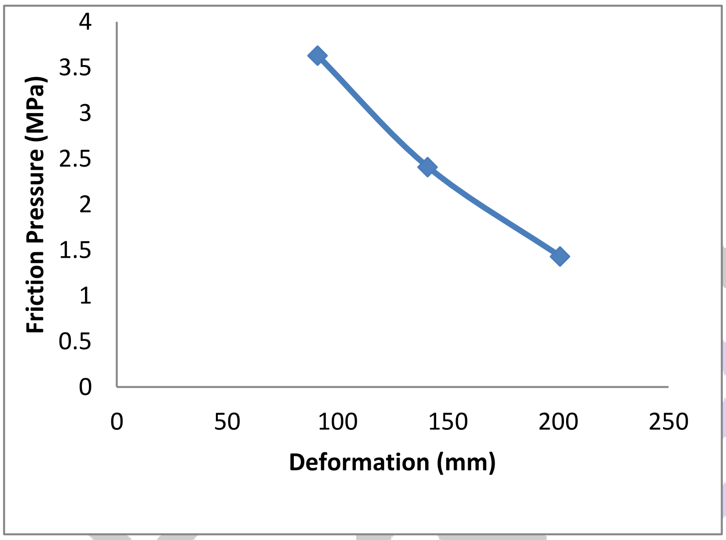

Fig 8 Relation between Deformation and Friction Pressure

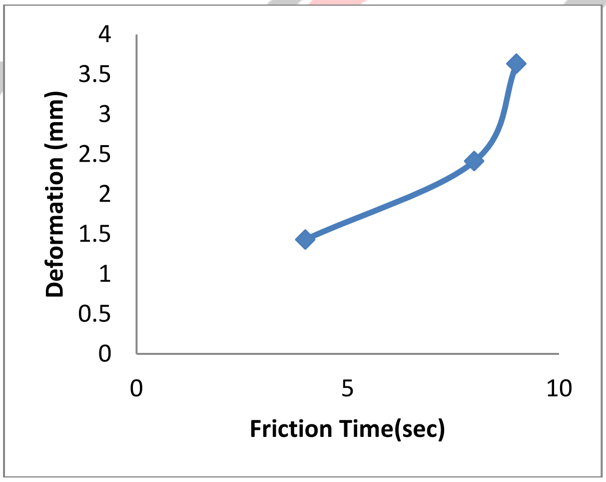

Fig 9 Relation between Deformation and Friction Time

Vickers Hardness Result

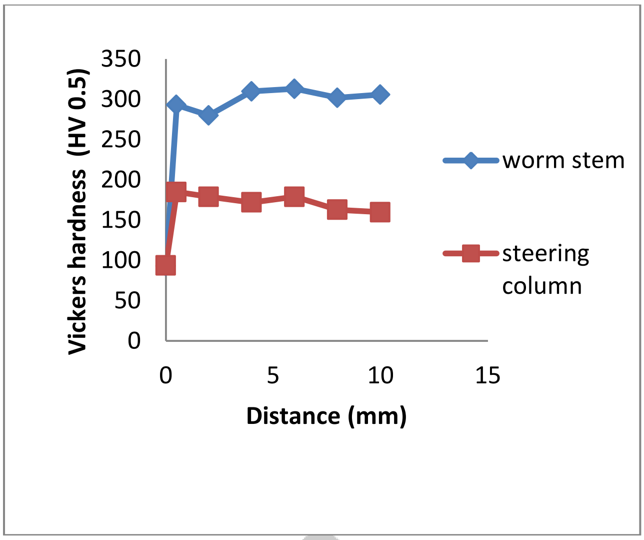

Fig 10 Distributions of hardness on Horizontal Distance of Weld Joints for Trial1.

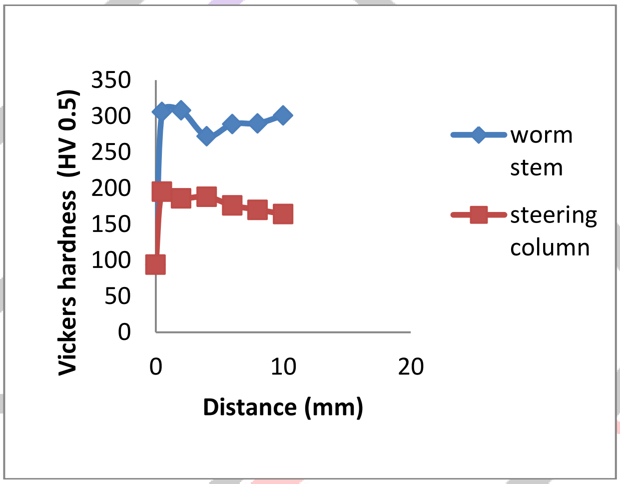

Fig 11 Distributions of hardness on Horizontal Distance of Weld Joints for Trial2.

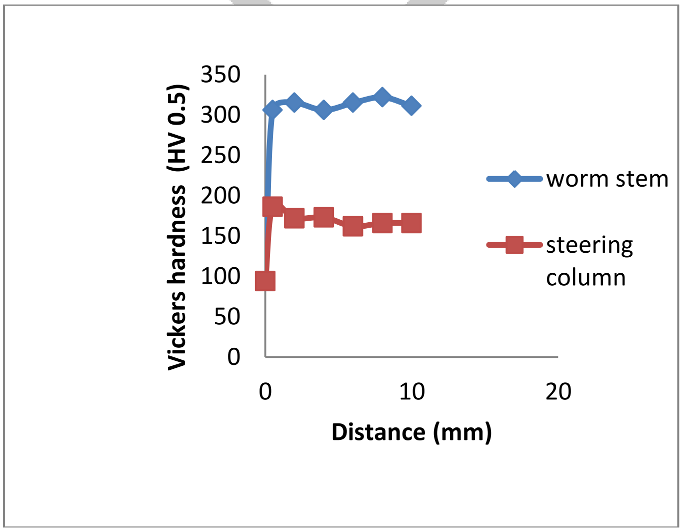

Fig 12 Distributions of hardness on Horizontal Distance of Weld Joints for Trial3.

Finite Element Analysis

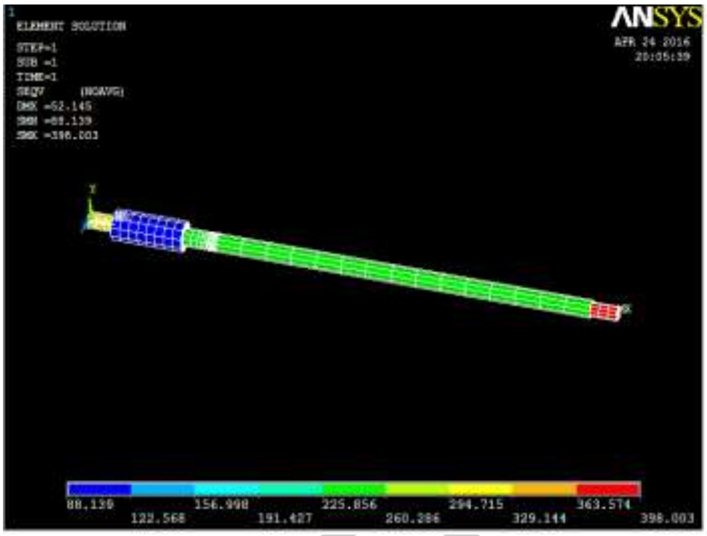

Fig 13Von Mises Stress for Tension

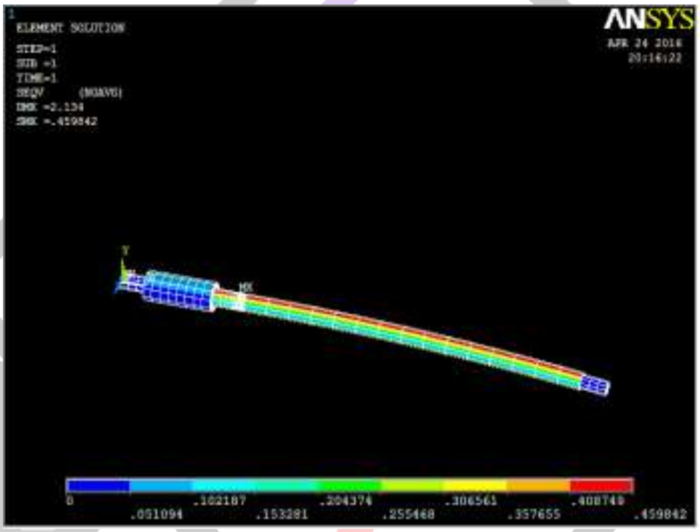

Fig 14 Von Mises Stress for Torsion

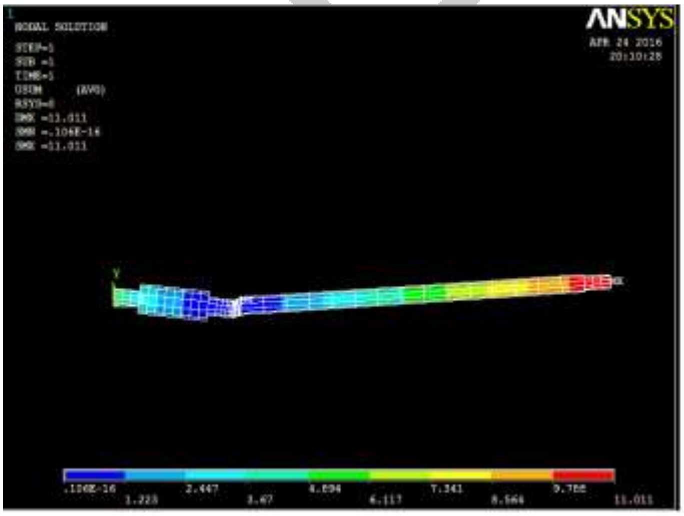

Fig 15 Displacement vector sum for Bending

For an applied load of 65 kN, the Tensile strengths for steering column and worm stem welded joint, theoretically is 323.38 MPa. But in the experiment we got 322.1 MPa (show in table 3) which is lesser than theoretical value so in order to increase tensile strength of the joint there is a need to increase the friction pressure. FEA result of tensile stress is 398.03MPa (shown in fig 13)

The graph 6 represents the relation between tensile strength and friction pressure. In graph we can see as increasing of friction pressure the tensile strength is increasing and it gives almost safe stress and 7 shows the relation between tensile strength and friction time. In plot we got solution if the friction time decrease the tensile strength will increase an also this friction time effecting the hardness of the material.

Bending test results are based on deformation of welding joint. Theoretically, for 40kN load deformation is 0.136 mm, but in the experiment we got 3.63 mm (shown in table 4) and which is failing. By this we can conclude bending strength of the material directly depending on the friction pressure while welding. In FEA deformation is 11.011 mm and it will also fail (shown in 15 fig).

The graph 8 represents the relation between deformation and friction pressure. In graph we can see as increasing of friction pressure decrees in deformation and its gives almost safe material from fail and 9 shows the relation between deformation and friction time. In plot we got solution if the friction time decrease the deformation also decrees and also this friction time effecting the hardness of the material.

Obtained theoretical Shear stress in torsion is 15.71 MPa for 100 N.m torque. FEA results of the torsion are 2.314 MPa. (Shown in fig 14) Both theoretically and FEA, shear stress in torsion is safe.

Hardness of both materials in the Vickers hardness is obtained based on heat affected by friction weld. Steering column side hardness is uniform and Worm stem side hardness will decrease from 0.5 to 4mm horizontally, but which will not affect the failure. The Distributions of hardness on Horizontal Distance of Weld Joints graph 10,11and 12 indicates hardness of the material with distance.

IV CONCLUSION

The following results are obtained after comparing values of theoretical, experimental and FEA results.

1. The Tensile strengths and bending strength for steering column and worm stem welded joint, depends on the increase of the friction pressure and also maintain constant friction time.
2. The Tensile strengths and bending strength for steering column and worm stem welded joint, depends on case hardening process as well as method of friction welding process.
3. Both theoretical and FEA results shows, shear stress in torsion is safe.
4. Heat affected zone (HAZ) will not affect to the steering column and worm stem as obtained from the Vickers hardness test results.

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