Elimination of Cracks Formed on Rivet Head

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***Abstract*— This paper aims at successfully designing and manufacturing an entirely new riveting tool that would help in the production of defect free rivet heads. In the process of designing the new tool, this report also explains the design of a suitable rivet head that would withstand the stresses developed during the riveting operation. Also in an effort to increase the efficiency of riveting done within the organisation this report proposes to reduce the number of tools required for riveting, i.e. optimization of riveting operation.**

***Index Terms*— Rivet head, Riveting tool. Principal Stress**

I. Introduction

Often small machine components are joined together to form a larger machine part. Design of joints is as important as that of machine components because a weak joint may spoil the utility of a carefully designed machine part. Rivets are widely used in industrial applications for joining different machine components. Cracks developed on the rivet heads during their forming may lead to the failure of the entire machine. Hence it is very important to eliminate the formation of cracks. The possible reasons for this defect are improper tool design, machine fluctuations and improper material selection of the tool or rivet. In our effort to eliminate this problem redesigning the tool would be the most feasible and attractive option.

II. Materials and Methods

Design Procedure

The design procedure consists of designing the rivet head and the riveting tool.

Rivet Head Design:

Rivet Shank and Rivet Head Dimensions-

Equating the volume of rivet shank to the volume of the rivet head formed.

Volume of rivet shank = Volume of rivet head

By measurement,

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Shank diameter (d) = 6.0 mm

$r = \frac{d}{2} = 3.0$ mm

Shank height (h) = 6.3 mm

Volume of shank = $\pi r^2 h$ .... cylindrical shank

$= \pi\,(3.0)^2\,(6.3)$

$= 178.1283\ mm^2$

Hence, Volume of rivet head = 178.1283 mm^2

Constraints in design of rivet head-

Maximum height = 2.1 mm

Rivet head height exceeding 2.1 mm would lead to crashing of rivet head with pole cage.

Minimum height = 2.0 mm

Minimum rivet height is limited by riveting machine specifications.

Maximum diameter = 15 mm

Maximum diameter is limited by the space available for rivet head.

Minimum diameter = 10 mm

Minimum diameter is limited by riveting machine specifications.

Hence, designing the rivet head based on maximum permissible height[1].

Rivet head height = 2.1 mm

Volume of rivet head = 178.1283 mm^2

There exists a unique value of the rivet head diameter which would meet the above requirements.

Using trial and error method to find the most suitable rivet head diameter

Starting with minimum permissible rivet head diameter (d_{head}=10 mm) and approaching the maximum permissible diameter (d_{head}=15 mm)

Table 1 Dimension of rivet head

Sr. No.	Rivet Head height mm	Rivet Head diameter mm	Volume of rivet head mm^3	Radius of Curvature mm
1.	2.1	10	87.3159	7
2.	2.1	11	104.634	8.25
3.	2.1	12	123.601	9.62
4.	2.1	13	144.218	11.11
5.	2.1	14	166.484	12.72
6.	2.1	14.5	178.236	13.56
7.	2.1	15	190.399	14.44

Thus, with the aid of Pro-E software it is observed that the required conditions are met with rivet head diameter of 14.5 mm along with the radius of curvature equal to 13.56 mm.

Mathematical Derivation of Volume[2]-

h = 2.1 mm

d = 14.5 mm

Volume of rivet head = Volume of spherical section – Volume of Cone

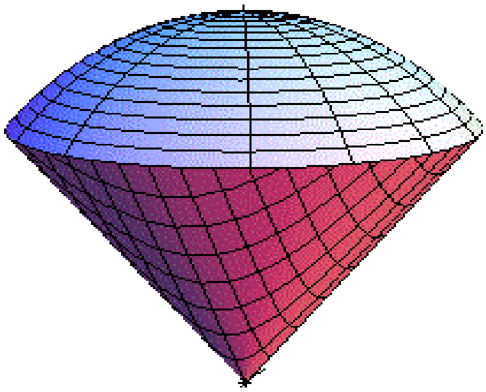

Fig. 1 Volume of Rivet Head

Volume = $\oiiint r^2 \sin\phi \, dr \, d\theta \, d\phi$

Limits for the above volume integration:

r = 0 to 13.56

θ = 0 to 2π

ϕ = 0 to 32.3209° = 0 to 0.5641

Volume of Spherical section $= \oiiint_0^{13.56} (r^2 \, dr) \sin\phi \, d\theta \, d\phi$

$= \oiint_0^{0.5641} (\sin\phi \, d\phi) \, d\theta \, [r^3/3]$

$= \oint_0^{2\pi} (d\theta) \, [-\cos\phi] \, [r^3/3]$

$= [\theta] \, [-\cos\phi] \, [r^3/3]$

$= (2\pi - 0) \, \{-[\cos(0.5641) - \cos(0)]\} \, (13.56^3/3 - 0)$

$= 2\pi \, (-0.845 + 1) \, (831.1086)$

$= 809.911 \text{ mm}^3$

Volume of Cone $= \frac{\pi r^2 h}{3}$

$= \frac{\pi (7.25)^2 (11.46)}{3}$

$= 631.0503 \text{ mm}^3$

Volume of Rivet Head = 809.911 – 631.0503

= 178.8606 mm^3

Hence, it is proved mathematically that for given rivet head height of 2.1 mm and rivet head volume of 178.236 mm^3, the rivet head diameter is equal to 14.5 mm.

Checking rivet head for failure-

Riveting machine capacity = 2 ton

Assuming that the force applied is uniformly distributed over the rivet head.

Force acting on rivet head, F $= \frac{20000}{14.5} = 1380$ N

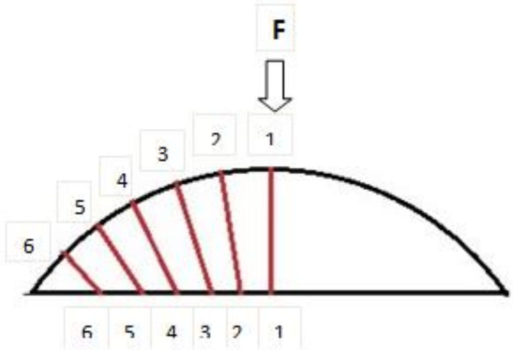

Fig. 2 Front View of Rivet Head

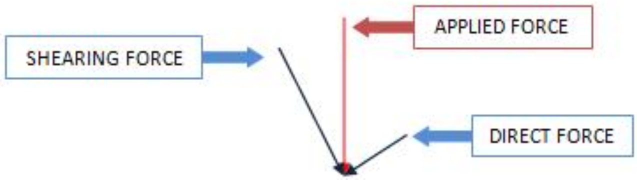

Fig. 3 Components of Applied Force

Checking the stresses developed at various sections.

Table 2 Calculation of Direct and Shearing force[3]

Sr. No.	Section	Area mm^2	Inclination θ	Shearing Force F cos(θ) N	Direct Force F sin(θ) N
1	1-1	20.6367	0	1380	0
2	2-2	19.9040	5.3868	1373.905	129.553
3	3-3	17.7247	10.7737	1355.675	257.964
4	4-4	14.1730	16.1605	1325.470	384.094
5	5-5	9.4489	21.5473	1283.558	506.831
6	5-5	4.0893	26.9341	1230.308	625.092

Table 3 Calculation of Principal Stress[4]

Section	Direct Stress MPa	Shear Stress MPa	Principal Stress MPa
1-1	0	66.871	66.871
2-2	6.508	69.026	72.356
3-3	14.554	78.477	86.090
4-4	27.100	93.520	108.046
5-5	53.639	135.842	165.283
6-6	152.860	300.860	386.846

III. Material Selection-

Steel 220 M07 (En1A), Grade BS970

Ultimate Stress = 480 MPa

Observation-

Stress developed in various sections of the rivet head are less than the maximum permissible stress of material.

Result-
Design of rivet head is safe.

Riveting Tool Design:

Tool Design-
Riveting is a cold forming process[5]. Thus the shape of the rivet head and that of the riveting tool should be identical[6].

Tool Dimensions-
Tool depth = 2.1 mm; Tool diameter = 13.5 mm; Radius of curvature = 13.56 mm

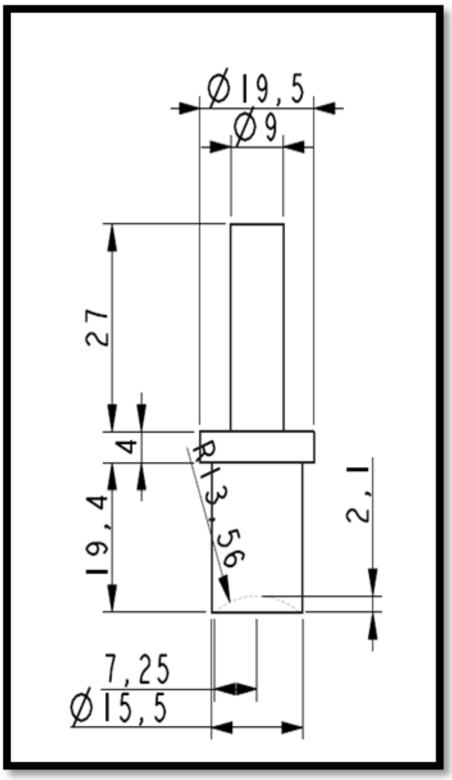

Fig. 4 Riveting Tool Design

Observations-
- On performing riveting operation with the above tool it was observed that the rivet head formed was unsatisfactory. This was on account of the assumption that the tool rotates about a vertical axis.
- However, in reality the tool in orbital riveting operation is inclined at an angle of 4 to 8 degrees with the vertical[7]. In case of the riveting machine under consideration this inclination was found to be 8 degrees.
- The inclination contributed to the defect in the following ways:
  - The volume generated by the rotation of the tool designed above was much greater than the volume of the rivet shank.
  - This excess volume available led to improper flow of material during cold forming process.
- Hence a modification in the tool design became necessary.

Redesigning the riveting tool-
In order to modify the tool the following conditions must be satisfied:

- The tool depth and diameter must decrease. This became possible only because our initial design was based on maximum permissible height[8].
- The radius of curvature of the tool must remain same in order to ensure that the rivet head geometry was not disturbed[9].

This was achieved by varying the depth and diameter of the rivet tool and calculating the volume enclosed by the rotating tool.

IV. Calculations-

Radius of curvature = 13.56 mm

Table 4 Calculation of Volume generated by rotating tool

Sr. No	Tool depth	Tool diameter	Volume enclosed when stationary	Volume enclosed during rotation
1	2.1	14.5	178.236	237.669
2	2.0	14.174	161.977	218.195
3	1.9	13.844	146.592	198.657
4	1.8	13.5	131.879	179.871

New Dimensions-
Depth = 1.8 mm
Diameter = 13.5 mm
Radius of Curvature = 13.56 mm

Observation-
Tool manufactured with above dimensions provided satisfactory results during operation.

Result-
Tool is acceptable for use.

Tool Design-
Tool depth = 1.8 mm
Tool diameter = 13.5 mm
Radius of curvature = 13.56 mm

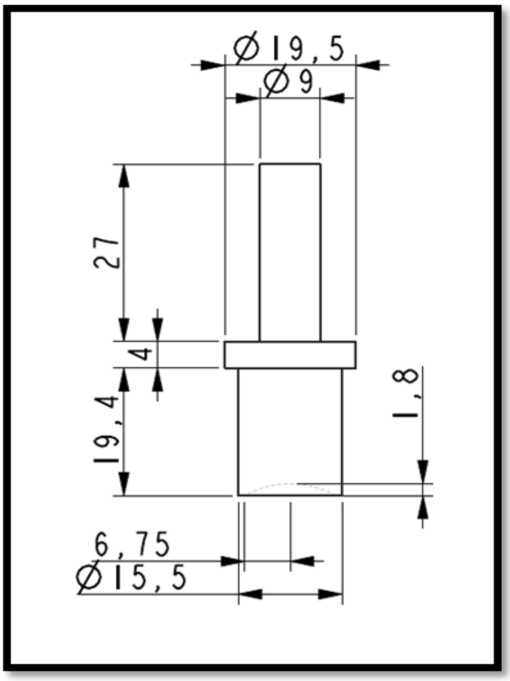

Fig. 5 Riveting tool design considering rotation

Riveting Operation-
Depending upon the rivet head size to be formed the riveting machine can be adjusted to meet the varying requirements. This is achieved by making use of the timer provided with the riveting machine[10].
To obtain the best result it is important that the timer be set to the correct duration to avoid

- Improper head formation due to insufficient operating time
- Formation of a ring on the plate due to excess operating time

Timer Details-

Table 5 Timer details

Timer	Time			Total Time (sec)
	Downward Stroke (sec)	Riveting (sec)	Upward Stroke (sec)	
7.5	0.6	0.4	0.6	1.6
10	0.6	1.1	0.6	2.3
11	0.6	1.3	0.6	2.5
12.5	0.6	1.4	0.6	2.6
15	0.6	1.6	0.6	2.8
17.5	0.6	1.9	0.6	3.1
20	0.6	2.2	0.6	3.4
22.5	0.6	2.4	0.6	3.6
25	0.6	2.9	0.6	4.1
27.5	0.6	3.1	0.6	4.3
30	0.6	3.4	0.6	4.6

V. OBSERVATION-

The best result was obtained with timer set to 17.5 with an operating time of 2 seconds in addition to the tool downward and upward motion of 0.6 seconds each.
Hence total operating time = 3.1 seconds

Optimization of Riveting operation at Larsen and Toubro:

Steps involved-

1. Collection of data on all riveting operations performed within the organisation.
2. Recording the dimensions (diameter and height) of the rivet shank.
3. Calculating the volume of all rivet shanks.
4. Regrouping rivet shanks having almost same volume together.
5. Designing rivet heads based on rivet shank volumes.
6. Designing riveting tool for the rivet heads designed.
7. Using one tool for same rivet head volumes.
8. Designing of individual tools.

The design procedure shown above is for Tool No. 09. Similar design approach can be adopted for all tools.

Data on different rivets manufactured at L&T-

Table 6 Rivet data

Assembly CAT No.	Plate Thickness	Cylinder Dimension			Volume of Cylinder (mm^3)	Tool No.
		Diameter (mm)	Height (mm)	Used Height (mm)		
SL91660	2	2.4	4	2	9.05	1
SL90761	1.6	2.5	3.5	1.9	9.33	
SL90802	6	2.1	8.5	2.5	8.66	
SL90728	3	4	6	3	37.70	2
SL90858	2.5	4	5.5	3	37.70	
SL90860	2.5	4	5.5	3	37.70	
SL90861	2.5	4	5.5	3	37.70	
SL92722	2.5	4	5.5	3	37.70	
SL92868	2.5	4	5.5	3	37.70	
SL90858	2.5	5.2	5.8	3.3	70.08	3
SL90860	2.5	5.2	5.8	3.3	70.08	
SL90861	2.5	5.2	5.8	3.3	70.08	
SL92722	2.5	5.2	5.8	3.3	70.08	
SL92868	2.5	5.2	5.8	3.3	70.08	
SL90788	1.5	5	5.1	3.6	70.69	
SL90792	2	5	5.6	3.6	70.69	
SL90760	16	5	20	4	78.54	4
SL92871	16	5	20	4	78.54	
SL90749	2.7	4.9	6.9	4.2	79.20	
SL90749	2.7	4.9	6.9	4.2	79.20	
SL91963	2.7	4.9	6.9	4.2	79.20	
SL91963	2.7	4.9	6.9	4.2	79.20	
SL90717	3	6	7.5	4.5	127.23	5
SL92074	3	6	7.8	4.8	135.72	6
SL90730	4	6	9.3	5.3	149.85	7
SL90760	16	6	21.5	5.5	155.51	8
SL92871	16	6	21.5	5.5	155.51	
SL90751	3	6	9.3	6.3	178.13	9

Rivet Head Design-

Table 7 Design of rivet heads

Assembly CAT No.	Volume of Cylinder	Tool No.	Radius of Curvature R (mm)	Rivet head diameter D (mm)	Rivet head height h (mm)	Design Volume (mm^3)
SL91660	9.05	1	4	5	0.9	9.15
SL90761	9.33					

SL90802	8.66					
SL90728	37.70	2	4	7	1.7	37.14
SL90858	37.70					
SL90860	37.70					
SL90861	37.70					
SL92722	37.70					
SL92868	37.70					
SL90858	70.08	3	8	10	1.7	70.02
SL90860	70.08					
SL90861	70.08					
SL92722	70.08					
SL92868	70.08					
SL90788	70.69					
SL90792	70.69					
SL90760	78.54	4	8	10.5	1.7	79.73
SL92871	78.54					
SL90749	79.20					
SL90749	79.20					
SL91963	79.20					
SL91963	79.20					
SL90717	127.23	5	10.5	12.5	2	128.14
SL92074	135.72	6	11	13	1.9	134.26
SL90730	149.85	7	10.5	13	2.1	147.46
SL90760	155.51	8	9.5	13	2.1	153.82
SL92871	155.51					
SL90751	178.13	9	13.5	14.5	2.1	178.24

Result- All 28 riveting operations performed at L&T can be completed using only 9 tools.

VI. Results and Discussion

Defect free rivet heads are formed with a tool having the following dimensions:
Tool Depth : 1.8 mm
Tool Diameter : 13.5 mm
Radius of Curvature : 13.56 mm

Any tool having dimensions exceeding the above would give cracks on the rivet head as it would generate a larger volume leading to excess flow of material. This results in weaker sections being developed on the rivet head. Tools having dimensions less than those mentioned above would lead to incomplete riveting. Both these would lead to the formation weak joints which is undesirable.

The formation of rings could be attributed to the long periods for which the tools are put to use. High life cycles coupled with the heat generated at the contact surface leads to adhering of the rivet material to the inner surface of the tool. Owing to this there is a reduction in the effective depth of the tool. To overcome this defect a compromise is made with the operation time, employing a higher operation time to counter the effect of the reduced volume. Improving the material of the tool is worth consideration.

Another approach to counter this effect is to employ a tool having dimension greater than those mentioned above. However this would lead to excess volume generated during riveting operation leading to improper material flow.

The tools being used in Larsen and Toubro were most likely to have dimensions exceeding those mentioned above leading to weaker rivet heads. This would be the most likely reason for cracks being observed in the rivet heads manufactured with new tools.

However this presumption couldn't be verified due to the absence of data related to the riveting tools.

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