OPTIMIZATION OF SNAP DESIGN PARAMETERS TO AVOID BURSTING AND RING FORMATION OF RIVET

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ABSTRACT

Riveting is an old material forming process and it is a temporary joint used to join thin pieces of metal sheets. This paper presents design of snap which is used in riveting process. The main objective of paper is to optimize snap design parameter to avoid bursting and ring formation of rivet and identify stress develop in rivet due to force acting by a snap. Rivet should be a semi-tubular in shape. This design is based on volume of shank, material of shank and machine specification of riveting process. The problems occurs in riveting process because of over and under design of snap design parameters. Snap with optimize design parameter avoids bursting and ring formation around rivet. To avoid bursting of rivet, principle stress induced due to snap force should be less than the material ultimate strength.

Key words: Bursting of Rivet and Ring Formation Around Rivet, Snap Design, Stress Analysis of Rivet.

I. INTRODUCTION

The manufacturing technology development is a driving factor of joining technique development using various material forming techniques [25]. Riveting is a technique used to join thin pieces of metal sheets. This is a quick, cheap and single-step technique, using a semi-tubular rivet to fix the sheet components into a mechanical joint [23]. A riveting process has two parts, the snap and the rivet. Rivet pliers is used to pull the pin through the rivet and as this happens the rivet is deformed slightly so that it joins the metal pieces. This joint is ideal when the metal is thin and where the joint does not have to be very strong. A solid rivet has a manufactured head on one end and a solid shank on the other end by applying pressure on shank [2]. The shank of the rivet can be produced with a straight cut-off or a chamfered cut-off end. A die point can be manufactured into the
shank end to aid alignment during assembly. Common head styles are oval, truss, round, button, universal, pan, countersunk and flat.

Orbital Riveting Process is one of cold forming processes of metals [5] [20] in which an orbiting tool held at a fixed angle (3° to 6°) [7] is used to progressively move malleable material into a desired, predetermined shape. This process is used to form head, swage, crown and flare of malleable material and is used most often in fastening and assembly. This process produces a high quality head form without disturbing of component material grain structure. Orbital riveting machines have a spinning forming tool, called as a snap which is gradually lowered into the rivet. This snap spreads the material of the rivet into a desired shape depending upon the design of the tool.

Snap is one type riveting tool [19]. Possibly the lowest die and punch load force is the crucial factor from the snap lifetime point of view [26]. The snap contacts the material and then presses it while rotating until the final form is achieved. Rivet shank under compression is proposed that takes into account the friction between the rivet and the snap [21]. The final form often has height and diameter specifications, it is called rivet design parameter. Strength of rivet depends on rivet design parameter, material of rivet, and riveting direction [22].

Orbital forming machines offer the user more control over the riveting cycle but the trade off is in cycle time which can vary from 2 to 3 seconds [12]. There are different types of riveting machines. Each type of machine has unique features and benefits. An equation derived based on assuming a zero volume change of the rivet during plastic deformation [24]. The effect on the rivet geometry is depend on stress developed due to force applied by the snap [27].

Old design of snap has created two basic problems, bursting of rivet & Ring formation around rivet. Design parameter of snap is depending on constrain parameter of rivet which related to machine specification (Table1). Design parameters of snap is less than the constrain value of rivet that cause bursting of rivet (Fig.1). This bursting of rivet takes place due to deposition of material in centre of snap (Fig.2). Design parameter of snap are greater than the design constrain parameter value of rivet, it cause ring formation around rivet (Fig.3).

To avoid this two basic problem, we have to design new snap. In new design of snap, we have to consider three parameter related to snap, Diameter of snap (D), Radius of curvature of snap (R), Depth of snap (H). To optimize this parameter, we are using machine specification parameter (Table1) which is related to shank which is to convert into rivet.

Fig.1: Bursting of rivet
Fig. 2: Deposition of shank material in centre of snap

Fig. 3: Ring formation around rivet

Table 1: Machine specification parameter related to shank

<table>
<thead>
<tr>
<th>r No</th>
<th>Shank diameter ($d_1$)</th>
<th>Minimum Height of rivet (h)</th>
<th>Minimum diameter of rivet (d)</th>
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<tbody>
<tr>
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<td>3.30</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4: Orbital Riveting: Machine, Snap and Contact Area [13]
II. RIVET DESIGN

Fig.5: Shank and Rivet

\[ d_1 = \text{Diameter of shank used for rivet} \]
\[ r_1 = \text{Radius of shank used for rivet} \]
\[ h_1 = \text{Height of rivet used for rivet} \]
\[ h = \text{Height of rivet} \]
\[ d = \text{Diameter of rivet} \]
\[ R_1 = \text{Radius of curvature.} \]

Volume of rivet shank = Volume of rivet
By measurement,
Shank diameter used for rivet \( (d_1) = 4.9 \text{ mm} \)
\[ r_1 = \frac{d_1}{2} = 2.45 \text{ mm} \]
Shank height used for rivet \( (h_1) = 4.2 \text{ mm} \)
Volume of shank used for rivet \( = \pi r_1^2 h_1 \)
\[ = 79.20 \text{ mm}^3 \]
Hence, Volume of rivet = 79.20 \text{ mm}^3

1.1 CONSTRAINTS IN DESIGN OF RIVET

Maximum height \( (h) = 2.1 \text{ mm} \)
Minimum height \( (h) = 1.6 \text{ mm} \)
Height constraint - \( 2.1 \leq h \leq 1.6 \) \hspace{1cm} (1)

Rivet height exceeding 2.1 mm would restrict moment of assembly. Minimum rivet height is depending on riveting machine specifications (Table1).

Maximum diameter \( (d) = 10.5 \text{ mm} \)
Minimum diameter \( (d) = 8.30 \text{ mm} \) (Table1)
Diameter constraint – \( 10.5 \leq d \leq 8.3 \) \hspace{1cm} (2)

Maximum diameter constrain by the space available for rivet. Minimum diameter is depending upon riveting machine specifications.
1.2 PROBLEM DEFINITION

Volume of rivet \( V \) = 79.29 mm\(^3\)

Designing the rivet based on Maximum Permissible Diameter. [12]

Rivet Diameter \( (d) \) = 10.5 mm

Diameter constraint \( d \) - \( 10.5 \leq d \leq 8.3 \) from (2)

Height constraint \( h \) - \( 2.1 \leq h \leq 1.6 \) from (1)

Our target is to optimize snap design parameter which is height \( h \) and radius of curvature \( R \) to avoid bursting and ring formation around rivet. With the help of above constraint of we find rivet height which satisfied our volume requirement. Rivet is in form of spherical shape. Starting with maximum permissible rivet height \( h_{rivet} = 2.1 \) mm and approaching the minimum permissible height \( h_{rivet} = 1.6 \) mm. We are finding Radius of Curvature of Rivet \( R \) and Volume of Rivet \( V \) help of modeling software CATIA 5-V19.

Table 2: Rivet Design Parameter

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Height of Rivet ( h )(mm)</th>
<th>Diameter of Rivet ( d )(mm)</th>
<th>Radius of Rivet ( r )(mm)</th>
<th>Radius of Curvature of Rivet ( R )(mm)</th>
<th>Height of cone ( R-h ) ( (\text{Degree}) )</th>
<th>( \phi ) (Degree)</th>
<th>( \phi ) (Radian)</th>
<th>Volume of Rivet ( V )(mm(^3))</th>
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</tbody>
</table>

The required volume is met with rivet height of 1.8 mm along with the radius of curvature equal to 8.56 mm.

We further prove it mathematically,

Volume of rivet = 80.94 mm\(^3\)

When, Rivet Height \( h \) = 1.8 mm,

Diameter \( d \) = 10.5 mm and

Radius of curvature of Rivet \( R \) = 8.56 mm.

1.3 CHECKING VOLUME OF RIVET BY TRIPLE INTEGRATION METHOD [16]

Converting Cartesian co-ordinates into spherical co-ordinates,

\[ x = g(\rho, \phi, \theta) \]
\[ y = h(\rho, \phi, \theta) \]
\[ z = k(\rho, \phi, \theta) \]
\[
\iiint f(x, y, z) \, dV = \iiint f(g(r, \phi, \theta), h(r, \phi, \theta), k(r, \phi, \theta)) \left| \frac{\partial^2(x, y, z)}{\partial(r, \phi, \theta)} \right| \, dudvdw
\]
\[
dV = \left| \frac{\partial(x, y, z)}{\partial(r, \phi, \theta)} \right| \, dudvdw
\]
Here are the conversion formulae for spherical co-ordinates:
\[
x = r \sin \phi \cos \theta
\]
\[
y = r \sin \phi \sin \theta
\]
\[
z = r \cos \phi
\]
The following restrictions are applicable on the co-ordinates:
\[r \geq 0\]
\[0 \leq \phi \leq \pi\]
The Jacobian is given as,
\[
\begin{vmatrix}
\frac{\partial x}{\partial r} & \frac{\partial x}{\partial \phi} & \frac{\partial x}{\partial \theta} \\
\frac{\partial y}{\partial r} & \frac{\partial y}{\partial \phi} & \frac{\partial y}{\partial \theta} \\
\frac{\partial z}{\partial r} & \frac{\partial z}{\partial \phi} & \frac{\partial z}{\partial \theta}
\end{vmatrix}
\]
\[
= \begin{vmatrix}
\sin \phi \cos \theta & -r \sin \phi \sin \theta & r \cos \phi \cos \theta \\
\sin \phi \sin \theta & r \sin \phi \cos \theta & r \cos \phi \sin \theta \\
\cos \phi & 0 & -r \sin \phi
\end{vmatrix}
\]
\[
= -r^2 \sin^3 \phi (\cos \theta)^2 - r^2 \sin \phi (\cos \phi)^2 (\sin \theta)^2 + 0 - r^2 (\sin \phi)^3 (\sin \theta)^2
\]
\[
- r^2 \sin \phi (\cos \phi)^2 (\cos \theta)^2
\]
\[
= -r^2 (\sin \phi)^3 (\cos \theta)^2 (\sin \theta)^2 - r^2 \sin \phi (\cos \phi)^2 ((\cos \theta)^2 + (\sin \theta)^2)
\]
\[
= -r^2 (\sin \phi)^3 - r^2 \sin \phi (\cos \phi)^2
\]
\[
= -r^2 \sin \phi ((\sin \phi)^2 + (\cos \phi)^2)
\]
\[
= -r^2 \sin \phi
\]
Finally, \(dV\) becomes,
\[
dV = | - r^2 \sin \phi | \, dr \, d\theta \, d\phi
\]
\[
= r^2 \sin \phi \, dr \, d\theta \, d\phi
\]
Volume = \[ \iiint (R1)^2 \sin \phi \, dr \, d\theta \, d\phi \]
Since the values of \(\phi\) are in the range of \[0 \leq \phi \leq \pi\], there is no need of the absolute bars on the sine.
Limits for the above volume integration:
(R1) = 0 to 8.56
θ = 0 to 2π
φ = 0 to 37.80° = 0 to 0.65974 radian

Volume of Section of sphere used for Rivet =
\[ \frac{2\pi}{0} \frac{0.65974}{0} \frac{8.56}{0} (R1)^2 \sin \phi \, dR1 \, d\phi \, d\theta \]
= 275.25 mm³

Volume of Cone used for Rivet = \( \frac{\pi}{3} \) \( (\text{radius of cone})^2 \times (\text{height of cone}) \)
= 194.97 mm³

Volume of rivet = Volume of spherical section – Volume of Cone
= 80.28 mm³

Hence we have proved it beyond that for given rivet height (h) = 1.8 mm and rivet diameter (d) = 10.5 mm and radius of curvature (R1) = 8.56 mm, rivet the volume is 80.28 mm³ with the help of triple integration method.

III. SNAP DESIGN

Assumptions for snap design
1) Riveting is a cold forming process [5], the shape of the rivet and that of the riveting snap are identical [6].
2) Snap design was based on maximum permissible Diameter. i.e. Diameter of Snap must remain same throughout design procedure [12]

3) Snap rotates about a vertical axis of machine.
   From above assumption, the dimension of Snap is equal to dimension of rivet.
   Diameter of snap (D) = Diameter of Rivet (d) = 10.5 mm
   Depth of snap (H) = Height of Rivet (h) = 1.8 mm and
   Radius curvature of rivet (R1) = Radius of curvature of snap (R) = 8.56 mm.

After design of snap, we check for performance of snap, it found that the new rivet have ring around it. This Ring formation due to inclination snap with vertical axis of riveting machine. Snap in riveting operation is inclined at an angle of $\alpha=6^\circ$ which is shown in (Fig.4). The volume generated by the rotation of the designed snap is greater than the volume of the rivet shank. It is required to change the dimension of snap to avoid ring formation.

From assumption 2, we have scope to change depth of snap (H) and radius of curvature of snap (R). To achieve required volume, the Snap depth (H) would be decrease and Radius Of curvature (R) would be increase. The diameter the Snap must remain same to avoid disturbance in geometry of rivet. We form the table by varying the snap depth (D) and radius of curvature of snap (R) and calculating the volume enclosed by the rotating snap with or without considering angular rotation.

<table>
<thead>
<tr>
<th>Sr No.</th>
<th>Snap depth (H)</th>
<th>Snap diameter (D)</th>
<th>Radius of Curvature (R)</th>
<th>Volume enclosed by snap without considering angular rotation (V1)</th>
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<th>Effect on rivet</th>
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<td>95.72</td>
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<td>Ring formation around rivet</td>
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</table>
IV. STRESS ANALYSIS OF RIVET

Machine used for riveting = light duty machine (Pneumatic operated) [13]
Pressure applied by Riveting machine = 5 bar = 0.5 N/mm²
Assuming that the pressure applied is uniformly distributed over the rivet head.

4.1 Material of riveting shank
Steel 220 M07 (En1A), Grade BS970, Bright round bar [6],
Ultimate Stress of En1A = 490*10³ KPa [6]
Force acting at various sections as shown in (Fig.7) and (Fig.9),

Table 3: Force acting at different sections

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Section</th>
<th>Pressure acting by the machine(P) (N /mm²)</th>
<th>Inclination ( \psi = (2\phi) )</th>
<th>Area of section ( (A_1) = \frac{4}{3} \pi R^2 )</th>
<th>Area of Triangle ( (A_2) = \frac{1}{2} \times (R1)^2 \sin(\psi) )</th>
<th>Area where force applied(mm²) ( (A) = (A_1 - A_2) )</th>
<th>Force acting at section(N) ( (F=P/A) )</th>
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Principle Stress developed at various sections,

Table 4: Principal Stress developed in different sections[18]

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<thead>
<tr>
<th>Sr. No</th>
<th>Section</th>
<th>Force acting at section(N) ( (F=P/A) )</th>
<th>Inclination ( \phi )</th>
<th>Direct Force (N) ( (F \sin(\phi)) )</th>
<th>Shearing Force (N) ( (F \cos(\phi)) )</th>
<th>Direct Stress (MPa)</th>
<th>Direct Stress (KPa)</th>
<th>Shear Stress (MPa)</th>
<th>Shear Stress (KPa)</th>
<th>Principal Stress (KPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>6.425</td>
<td>0</td>
<td>0</td>
<td>6.425</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>500</td>
<td>500</td>
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<tr>
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<td>3.82</td>
<td>6.3</td>
<td>0.064229</td>
<td>3.81946</td>
<td>0.00840695</td>
<td>8.40695</td>
<td>0.4999293</td>
<td>499.9293</td>
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<td>0.06707</td>
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<td>0.01681152</td>
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<td>41.98723</td>
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<td>498.234</td>
<td>519.669663</td>
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Fig.10: Principle Stress variation along inclination \( \phi \)
V. RESULT AND DISCUSSIONS

1) Inclination ($\phi$) is increasing then principle stress also increase. Principle stress is directly proportional to inclination ($\phi$) made by rivet shown in (Fig.10). Maximum principal Stress developed in the rivet is within the permissible ultimate stress limits.

2) Direct stress is very less as compare with shear stress therefore shear stress is responsible for formation of rivet head as shown in (Table 4).

3) Snap with depth (H) = 1.2mm, diameter (D) = 10.5mm and radius of curvature (R) = 8.56mm are avoiding bursting and ring formation of rivet. Table below shows all design parameter of Snap,

<table>
<thead>
<tr>
<th>r. No</th>
<th>Design Parameter of Snap</th>
<th>Design parameter value according rivet design concept</th>
<th>Design parameter value according snap rotation design concept</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diameter of snap (D) (mm)</td>
<td>10.5</td>
<td>10.5</td>
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<td></td>
<td>Depth of snap (H) (mm)</td>
<td>1.8</td>
<td>1.2</td>
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<td></td>
<td>Radius of curvature of snap (R) (mm)</td>
<td>8.56</td>
<td>12.08</td>
</tr>
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<td></td>
<td>Volume of rivet (V) (mm$^3$)</td>
<td>79.20</td>
<td>79.20</td>
</tr>
<tr>
<td></td>
<td>Volume enclosed by snap without considering angular rotation (V1) (mm$^3$)</td>
<td>80.94</td>
<td>52.83</td>
</tr>
<tr>
<td></td>
<td>Volume enclosed by snap with considering angular rotation (V2) (mm$^3$)</td>
<td>120.11</td>
<td>80.88</td>
</tr>
</tbody>
</table>

4) Volume enclosed by snap without considering angular rotation (V1) is equal to volume of rivet (V) then formation of ring occurred.

5) Volume enclosed by snap with considering angular rotation (V2) is equal to volume of rivet (V) then rivet produced by snap is called defect free rivet. shown in (fig.11)

6) Volume enclosed by snap with considering angular rotation (V2) is less than volume of rivet (V) AND volume enclosed by snap without considering angular rotation (V1) is less than volume of rivet (V) then bursting of rivet take place.
VI. CONCLUSION

1) Snap with optimize design parameter avoids bursting and ring formation around rivet.
2) To avoid bursting of rivet, principle stress induced due to snap force should be less than the material ultimate strength.
3) Volume of snap should be less than the volume of shank which has to rivet.
4) Reduce rejection due to bursting of rivet and ring formation around rivet.

VII. ACKNOWLEDGEMENT

The success and final outcome of this project required a lot of guidance and assistance from many people and we are extremely fortunate to have got this all along the completion of our project work. We would like to acknowledge the support of the management and the Engineering Department of Larsen and Toubro who gave us generous access to their manufacturing facilities and particularly of Mr. Anil Zore for providing such nice support and guidance. We owe our profound gratitude to Mr. S.S.Ahuwalia who encouraged us to pursue the subject relentlessly by taking keen interest in our project and guiding us throughout the duration of our project. We are thankful to our institution and faculty members without whom this project would have been a distant reality.

VIII. REFERENCES


