Increasing load transfer in bolted joints

with 3M™ Friction Shims

January 2017
3M Advanced Materials Division
Load transfer in bolted joints

1. **Shear Joint:** the applied loading is at right angles to the fastener axis

\[ F_N \times \mu > S \]

2. **Rotating or Torque Joint**

\[ \mu \cdot \frac{D\mu}{2} \cdot F_N > T \]

Both of these require two factors: preload, or clamping force, and friction.
What is Preload?

- A critical component of designing bolted joints is not only determining the number of bolts, the size of them, and the placement of them but also determining the appropriate preload for the bolt and the torque that must be applied to achieve the desired preload.

- One key aspect to appreciate is that the root cause of the majority of bolt/joint failures is due to insufficient preload. It is unusual for the bolt to be overloaded.

*If the preload provided by the bolt is insufficient, joint separation and movement can occur, resulting in possible bolt fatigue and self-loosening issues.*

Most bolt/joint failures are ultimately caused by insufficient preload.

\[
\begin{align*}
F_p &= \text{Preload Force} \\
F_c &= \text{Clamping Force} \\
F_s &= \text{Shear Force} \\
F_t &= \text{Tension Force}
\end{align*}
\]
Problems that can occur in bolted joints

- Bolt failure, or bolt shear
- Torsional loads
- Keyway or press-fit failures
Solutions to prevent failure

- Mechanical locking
- Prevailing torque
- Liquid locking compounds

However, none of these prevent loss of preload. What is the solution? Friction increase on the shear surface can help prevent loss of preload.
Relying on friction to transfer loads

Is this a recognized solution?

- What are standard friction coefficients?
- What are the methods of increasing friction?

Other types of shear joints rely on initial clamp load to resist slip. This type of joint requires a frictional force between the joint members. This type of joint is common in the structural steel construction industry and may be referred to as a friction-type or slip-critical joint.

_Bolted Joint Design – Fastenal Engineering_
Relying on friction to transfer loads

- Is this a recognized solution?
  - What are standard friction coefficients?
  - What are the methods of increasing friction?

A friction-type joint is one that has a low probability of slip at any time during the life of the structure. It is used where any occurrence of a major slip would endanger the serviceability of the structure and therefore has to be avoided.

*Guide to Design Criteria for Bolted and Riveted Joints*
Relying on friction to transfer loads

Is this a recognized solution?

- What are standard friction coefficients?
- What are the methods of increasing friction?

Since slip does not occur, these connections are appropriate in situations where slip of the connection is not acceptable, for example in cases involving repeated reversed load conditions or in situations where slip would result in undesirable misalignment of the structure. In slip-resistant joints, the fasteners are not actually stressed in shear, and bearing is not a consideration.

Guide to Design Criteria for Bolted and Riveted Joints
Relying on friction to transfer loads

Is this a recognized solution?

- What are standard friction coefficients?
- What are the methods of increasing friction?

When torsional loads are involved, it is desirable to have the shear load taken by frictional capacity in which case the actual load the bolt would see is zero.

_Sandia Guideline for Bolted Joint Design_
Relying on friction to transfer loads

• Is this a recognized solution?

What are standard friction coefficients?

• What are the methods of increasing friction?

0.2 for uncoated, non-lubricated metal surfaces that are cleaned by a qualified process and visibly clean at and after assembly.

0.1 for all other surfaces. This category includes nonmetallic (coated or uncoated) surfaces and metallic surfaces that are coated with any substance, including lubricant, paint, and conversion coating.

*NASA-STD-5020*
Relying on Friction to transfer loads

- Is this a recognized solution?
- What are standard friction coefficients?

What are the methods of increasing friction?

<table>
<thead>
<tr>
<th>Treatment of Surface</th>
<th>Coefficient of Friction (μ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel, not treated</td>
<td>0.20</td>
</tr>
<tr>
<td>Steel, shot blasted with 45μm ethyl zinc silicate coat</td>
<td>0.30</td>
</tr>
<tr>
<td>Steel, sand blasted</td>
<td>0.48</td>
</tr>
</tbody>
</table>

3M™ Friction Coating can increase the COF in excess of 0.75
What are 3M™ Friction Shims?

3M™ Friction Shims consist of a coated steel shim with partially embedded diamonds. When the shim is placed between two components in a bolted connection, the diamonds “bite” into the surface, creating a microform fit and significantly increasing friction between the two parts.

- Increase coefficient of friction ➔ transmit higher torque loads
- Drop-in solution ➔ easy to assemble and retrofit
- Reduce risk of slippage ➔ increase margin of safety
- Fit within close engineering tolerances
- Can be tailored to your specifications

3M™ Friction Shims are a simple, cost-effective way to reliably transmit up to 4x higher torque – without requiring modifications to the joint design.
Adding grip with 3M™ Friction Shims

The microscale form fit leads to an increase of the coefficient of static friction $[\mu_{\text{stat}}]$ by typically a factor 4, depending on material combination and surface parameters.
Static Friction: Test bench for $\mu_{\text{stat}}$ measurements

How to measure the coefficient of static friction $\mu_{\text{stat}}$?
Measurement principle of model test

Friction test bench at TU Chemnitz (Germany)

\[ \mu = \frac{2 \cdot T_R}{F_N \cdot D_R} \]

\[ D_R = \frac{2}{3} \cdot \frac{D_A^3 - D_I^3}{D_A^2 - D_I^2} \]
Static Friction: How to measure $\mu_{\text{stat}}$?

$\mu_{\text{stat}}$ is defined as $\mu_{0.1}$ (when $\varphi_{\text{max}} \leq 0.1^\circ \Rightarrow \mu_{\text{stat}}$ is defined as $\mu_{\text{max}}$).

Typical measurement curve for 3M™ Friction Shims and its evaluation:

- Initial slope (blue line) represents elastic response of measurement system – no slippage!
- Deviation from initial slope represents slippage.
- With given dimensions of the model test this is equal to a slippage of 20 $\mu$m.
3M™ Friction Shims: Examples of coefficients of static friction

<table>
<thead>
<tr>
<th>Material 1</th>
<th>Material 2</th>
<th>3M™ Friction Shim</th>
<th>Clamp load (MPa)</th>
<th>COF</th>
</tr>
</thead>
<tbody>
<tr>
<td>S690QL</td>
<td>GJS-700</td>
<td>None</td>
<td>115</td>
<td>0.16</td>
</tr>
<tr>
<td>S690QL</td>
<td>GJS-700</td>
<td>Grade 25</td>
<td>115</td>
<td>0.64</td>
</tr>
<tr>
<td>18CrNiCo7-6</td>
<td>GJS-700</td>
<td>Grade 25</td>
<td>115</td>
<td>0.66</td>
</tr>
<tr>
<td>GJS700</td>
<td>GJS700</td>
<td>Grade 25</td>
<td>50</td>
<td>0.73</td>
</tr>
<tr>
<td>S460</td>
<td>42CrMo4V</td>
<td>Grade 25</td>
<td>50</td>
<td>0.75</td>
</tr>
<tr>
<td>S460</td>
<td>S355</td>
<td>Grade 25</td>
<td>50</td>
<td>0.75</td>
</tr>
<tr>
<td>15-5PH SS</td>
<td>Ti-6Al-4V</td>
<td>Grade 25</td>
<td>75</td>
<td>0.71</td>
</tr>
</tbody>
</table>

S690QL: High tensile fine grained steel
18CrNiCo7-6: Case hardened steel
S460, S355: Structural Steel
Ti-6Al-4V: Titanium

GJS-700: Spheroidal graphite cast iron
42CrMo4V: Steel, quenched and tempered
15-5PH SS: Aerospace Stainless Steel

Note: For application specific data tests need to be carried out with test specimens made out of component representative material and surface machining.
3M™ Friction Shims: Typical automotive applications

3M™ Friction Shims help to increase power density in various powertrain applications.

Camshaft

Crankshaft

Flywheel
A solution for flexibility and safety

By increasing the level of static friction, 3M™ Friction Shims can help you both reduce component size and increase performance – all while allowing a greater margin for safety. That gives you the freedom and flexibility you need to design lighter, more powerful and reliable engines and power trains.

<table>
<thead>
<tr>
<th>μ without 3M™ Friction Shims</th>
<th>Additional μ with 3M™ Friction Shims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downsizing</td>
<td>Performance Increase</td>
</tr>
<tr>
<td></td>
<td>Safety Factor</td>
</tr>
</tbody>
</table>
Use 3M™ Friction Shims as a standard design element in order to help:

- Increase engineering design flexibility
- Reduce weight and component size
- Achieve power density targets with downsizing, increasing performance
- Increase safety factor with greater torque capacity
Thank you
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