Combating Embedment Relaxation in Bolted Joints

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If the earth shrunk to the diameter of a cue ball, it would be smoother than a cue ball. This can be hard for some to believe given the massive peaks and valleys on the earth's surface. The point is every surface has a certain amount of roughness. Even seemingly smooth metal surfaces can have peaks and craters under high magnification. *Figure 1* shows an aluminum bar using a SEM.

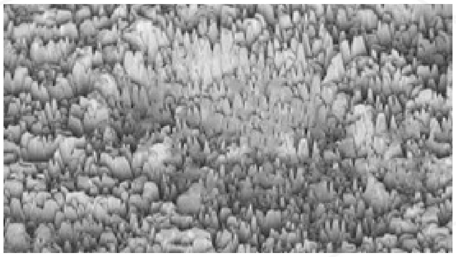

Figure 1

Bolted joints are widely used in engineering applications to create secure mechanical connections. However, one of the common challenges affecting the long-term reliability of these connections is embedment relaxation. This phenomenon results in a loss of preload over time, potentially leading to joint failure, leakage, or reduced structural integrity. This white paper explores the causes of embedment relaxation and outlines best practices to mitigate its effects.

What is Embedment Relaxation?

Embedment relaxation is the gradual loss of bolt preload due to microscopic flattening of surface roughness, material creep, or local yielding under compressive stress. It primarily occurs at the contact interfaces of the bolted components, including between the bolt head and the joint surface, nut and joint surface, and within the joint material itself. *Figure 2* shows a bolted joint and a magnified view of the many interface surfaces of the assembly. In the unloaded state, the surfaces only make contact at the high spots.

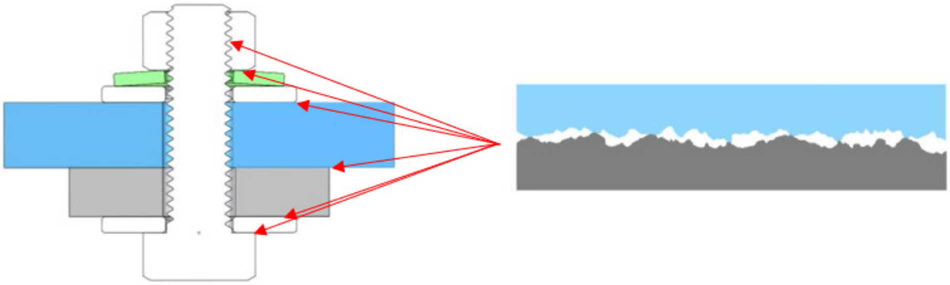

Figure 2

Under high load, these high spots yield (*Figure 3)*. The red lines show that the point contacts are spread over a larger area. Ultimately, the stresses are reduced to an equilibrium state where embedment stops.

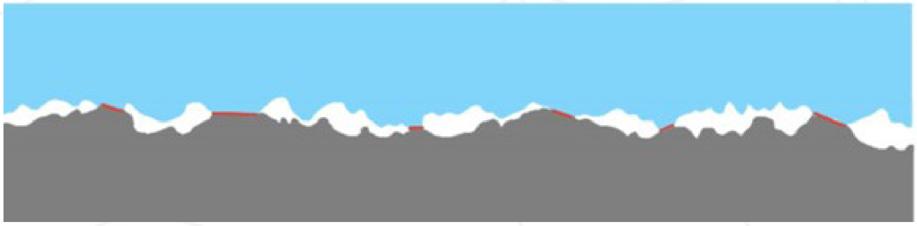

Figure 3

Effects of Embedment Relaxation

The primary consequence of embedment relaxation is a reduction in bolt preload, which can lead to:

- Loss of joint integrity and potential loosening.
- Increased risk of fatigue failure due to reduced clamping force.
- Leakage in pressure-sealed joints (e.g., piping systems, fluid connections).
- Reduced structural performance in critical applications (e.g., aerospace, automotive, and heavy machinery).

Factors that Influence Embedment Relaxation

It is estimated that many common bolted joints experience losses from 5% to 18% due to embedment relaxations depending on multiple factors.

1. ***Surface finish of interfacing surfaces.*** Rougher surfaces will usually experience more embedment and load loss.

2. ***The quantity of interfaces***. More interfacing surfaces will tend to have more yield than fewer.

3. ***The stress level in each surface relative to the yield strength of materials.*** More concentrated loads will lead to more loss of preload. In addition, softer materials will tend to yield more than those with high strength properties.

4. ***The elasticity in the bolting system.*** Elasticity does not necessarily reduce the amount of yielding that occurs. However, the effect of that yielding can be negligible with adequate bolting system elasticity.

Solution: Belleville Washers

Bellevilles can virtually eliminate any concern due to embedment relaxation by increasing the elasticity of the bolting system. As an example, consider a bolted joint that has a ½ inch steel bolt; a 1 inch grip length; and a 6000 lbf preload. This bolt would have a stretch of .002 in. If we were to assume that the embedment relaxation resulted in a 10% loss of load, then this would equate to about .0002 in of yielding. Now, if a Belleville was added to this system, the fastening system elasticity would increase to .022 and the loss of load would be (.0002/.022) less than 1%. More detail on how increased elasticity improves performance can be found at these links:

- Using Belleville Springs to Maintain Bolt Preload
- Why Bolts Work (and why some don't)
- Live Loading Using Solon Flange Washers

References:

Bickford, J. H., 1995, An Introduction to the Design and Behavior of Bolted Joints, Third Edition, Marcel Dekker, Inc., New York.

Bickford, J. H., & Nassar, S. (1998). Handbook of bolts and bolted joints. In CRC Press eBooks.

Embedding loss in bolted joints. (n.d.). Copyright 2021 Bolt Science Limited

Choosing the correct Belleville is critical. Solon Manufacturing Company offers a variety of application-specific tools and resources that can assist engineers in selecting the proper Belleville washer for their requirements, including:

Calculator: Infinite Bolt Fatigue Life Calculator
Calculator: Bolt Stretch Calculator
Application: General Purpose Bolting
Application: Commercial Bolting Application
Technical White Paper: Using Belleville Springs to Maintain Bolt Preload
Technical White Paper: Why Bolts Work (and why some don't)
Technical White Paper: Why Increased Elasticity Leads to Reduced Self-Loosening
Technical White Paper: Using Belleville Springs to Prevent Bolt Fatigue Failures
Video: Solon Belleville Spring Washers

For additional resources and information, visit www.solonmfg.com.

ABOUT THE AUTHOR

George P. Davet, BSME, MBA is President, Chief Engineer and Owner at Solon Manufacturing Company and has written and published numerous articles on the use and application of Belleville spring washers.
To learn more about Bellevilles and Solon Manufacturing, visit www.solonmfg.com, for technical resources such as case studies, white papers, product selection tools and videos.

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