Preload Relaxation in Aluminum PV Racking System Fasteners

Jon Ness, PE - October 2018

A critical, but often overlooked component within the aluminum PV Racking System is the threaded fasteners. Although relatively inexpensive components, fasteners connect components through joints which carry both static loads (live, dead, and snow loads) and dynamic loads (wind loads). In many PV Racking Systems, fasteners also create a reliable, low resistance electrical conduction path through the joint!

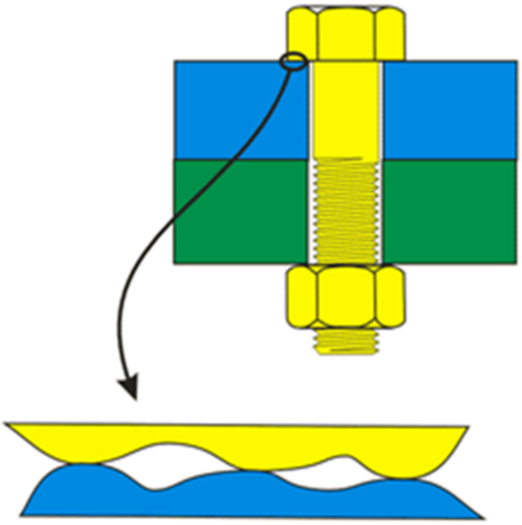
Examples of PV Racking System Fasteners

It is generally accepted that the design criteria for fastened joints exposed to dynamic loads is significantly more rigorous than the criteria for static loaded joints. In short, dynamically loaded joints must be designed and assembled such that in-service (residual) preload be sufficient to prevent the joint from opening (due to axial loading) and prevent the joint from slipping (due to shear loads). If this requirement is not met, there is a high likelihood that the fastener will fail eventually in the application. It's clear that the integrity of the PV racking joints is dependent on having consistent and sufficient preload in the fasteners.

A key advantage of threaded fasteners over other joining methods is that they can be dis-assembled and re-used. This feature is often the reason why threaded fasteners are used in preference to other joining methods. However, this feature is also a significant source of problems in PV racking systems. Unfortunately, there are several mechanisms which can cause threaded fasteners to loosen to the extent that they fail to carry the applied load and result in PV racking joint failures.

Effect of Embedment

The surfaces of a joint interface and fastener threads appear to be smooth, but, if you looked closer using a microscope you'd actually see the surfaces consist of ridges (asperities) and valleys. When two mating surfaces are brought together to create the joint, the microscopic ridges on both surfaces come in contact. When the fastener is tightened, very high localized stresses develop in the mating surfaces causing the plastic "flattening" of the load bearing surfaces. The localized flattening of the surfaces is frequently referred to as embedment. The tightening of the fastener results in it being stretched elastically. The amount of stretch the fastener experiences is surprisingly small. For small fasteners having a short grip length, and made from relatively "soft" materials like stainless steel, the stretch is typically less than .001". Hence, even small amounts of embedment can result in a significant loss of stretch and a corresponding loss of preload.



Magnified View Showing Asperity Contact in Joint
courtesy of Bolt Science

The greatest amount of embedment occurs while the fastener is being tightened and is compensated through the tightening process. Unfortunately embedment of the surfaces continues to occur even after the fastener is tightened, especially during the initial service loading cycles. Since most joints are not re-tightened after the initial assembly, the embedment which occurs in service results in a permanent relaxation of preload (loosening of the fastener).

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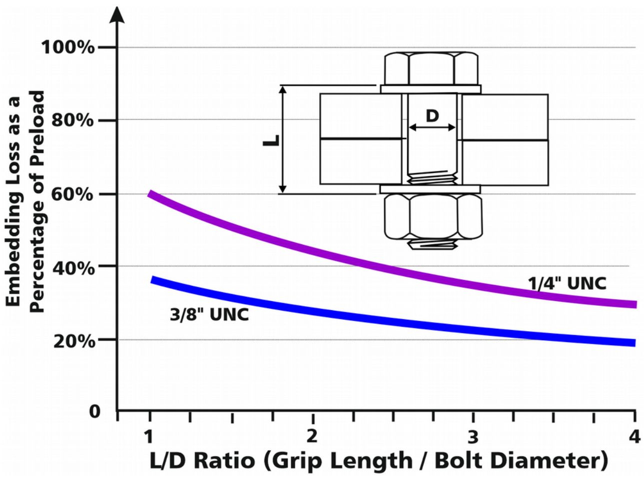
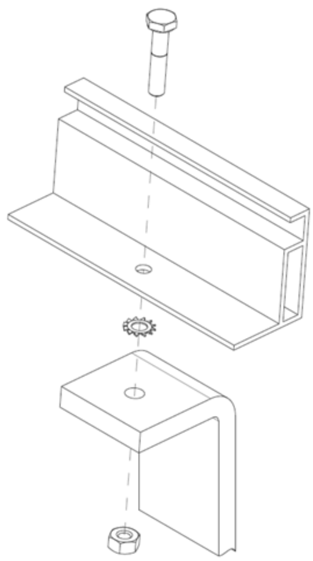
The amount of preload lost due to embedment for a specific joint depends upon a range of parameters including, the bolt and joint stiffness, the number of joint interfaces, the surface roughness, the material properties and the bearing stress. Under moderate surface stress conditions, typically less than 10% of the preload is lost within the first seconds after the joint is tightened. When the joint is subsequently dynamically loaded in the field, a further relaxation of preload occurs due to the pressure changes in the joint interfaces. In extreme cases, these losses can result in an additional 40% loss of preload. This loss occurs without any rotation of the fastener occurring.



courtesy of Bolt Science

Effect of Bonding Devices in Joint Interfaces

PV Racking systems must be grounded to protect personnel from the shock hazard which may become energized under electrical fault conditions. Aluminum racking components are typically anodized to protect against corrosion. This anodized surface is a natural insulator while the core aluminium remains electrically conductive. To ensure a continuous grounding connection, a 'star' washer or other device is often placed in the mounting system interface to pierce the outer anodized surface of the joint components when the joint is tightened. This connects the electrically conductive core aluminum in the mating components and reduces the joint electrical resistance.



Typical Bonded Racking System Bolted Joint

Similar to embedment, the piercing of the anodized surfaces results in plastic deformation in the joint. A portion of the plastic strain occurs during the initial tightening and this is compensated for through additional tightening. Plastic strain also occurs after the bolt tightening process is finished and especially when dynamic external loads are applied to the joint. As a result, a significant portion of the preload developed through tightening can be lost after the fastened and bonded joint is placed in service. This behaviour is difficult to quantify using the traditional design methods and is deserving of additional research.

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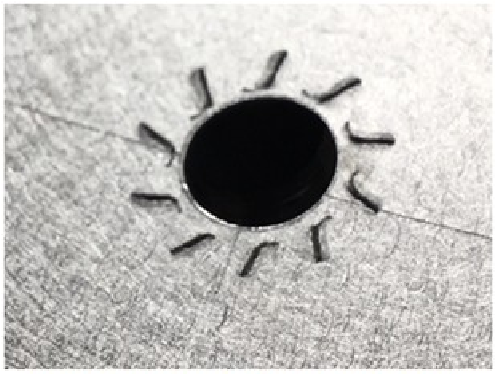
Typical Star Washer



Typical Plastic Deformation Seen in Bonded Interface

Fortunately, there are ways of reducing the preload loss due to embedment and plastic deformation in PV racking fasteners. Perhaps the most obvious way is to simply inspect and retighten the fasteners frequently after assembly and as the PV racking system enters service. Assuming the fasteners are tightened below their yield point, the preload relaxation in the joint will eventually diminish to a tolerable level. From a practical standpoint, repeatedly retightening the fasteners may not be realistic or even possible in some racking system installations. If you are unable to retighten the fasteners periodically, then the only real option is to live with the embedment and plastic strain by reducing the associated preload relaxation as much as possible. A way to do this is to lower the stiffness of the fastener so that it becomes less sensitive to the embedment and plastic deformation. This is frequently accomplished by increasing the grip length of the bolt and joint. Other means of reducing the stiffness of the fastener are available but out of the scope of this article. Regardless of how preload relaxation is addressed, it's critical that the factors of safety used in PV racking system fasteners are sufficiently high to account for the uncertainty surrounding preload relaxation.

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