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# Operational Experience with a Variety of Plasma Facing Tile Assemblies at JET

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## **ABSTRACT**

During the June 1999 JET shutdown, 3000 plasma facing Tile Assemblies were found to be loose and had to be re-torqued remotely using the Mascot force reflecting manipulator. Whilst the integrity of these Tile Assemblies has been monitored during previous man access shutdowns, with the introduction of tritium to the machine in May 1996, the majority had not been checked since March 1996.

This paper reviews typical plasma facing Tile Assembly designs within the JET torus and summarises the experience gained for use in future machine applications. This includes loosening processes/mechanisms and their prevention, applications of surface coatings to avoid seizing of un-lubricated assemblies, and the use of vibration resistant thread profiles. The design of attachments to minimise combined mechanical and thermal stresses in the tiles, material selection and other engineering aspects are also discussed.

## **1. INTRODUCTION**

During the June 1999 JET shutdown, 3000 plasma facing Tile Assemblies were found to be loose and had to be re-torqued remotely using the Mascot force reflecting manipulator. Whilst the integrity of these Tile Assemblies has been monitored during previous man access shutdowns, with the introduction of tritium to the machine in May 1996, the majority had not been checked since March 1996. This paper reviews the critical component parts of plasma facing assemblies within the JET torus and summarises the experience gained for use in future machine applications. The choice of tile materials, minimising of stresses, coatings and fixing integrity is discussed.

## **2. TILE MATERIALS AND CONTROL OF STRESSES**

Carbon Fibre Composite (CFC) is the standard material now used as plasma facing tiles at JET. Various properties are affected by the anisotropic nature of the material. Material strength and thermal conductivity are maximised along the fibre direction while thermal expansion is highest across the fibres. Thermal conductivity is affected by density variations during the carbon impregnation process and is improved with graphitisation but with a corresponding decrease in the mechanical strength. 2D materials are chosen where high thermal conductivity is essential while 3D materials are more suitable for structural applications where mechanical loads may be experienced on all axes. For 3D materials the increase in the principle properties along the third axis leads to a consequent reduction of the properties along the other axis, owing to the redistribution of fibres away from the main axis [1].

During the mid-1990's deterioration in the integrity of the Inner Wall Guard Limiter (IWGL, see Fig.1) tiles was observed. Significant cracks began to appear in the plane of the fibres in a high proportion of the tiles. For IWGL tiles, one of the principal fibre directions is perpendicular



*Fig.1: Inner Wall Guard Limiter (IWGL)*



*Fig.2: Modified IWGL Tile and tie rods*

to the contacting plasma to maximise thermal conductivity and reduce the tile surface temperature. However mechanical stresses caused by halo currents reacting with the poloidal and toroidal magnetic fields caused cracking in the plane of the fibres (delamination). Remedial action was therefore taken during the 1996 shutdown. The full inventory of IWGL, approximately 600 were removed from the Torus to an appropriate contamination controlled area, and holes drilled through the tile width to enable  $\text{\O}4\text{mm}$  alloy 718 tie rods to be fitted. A compression load was applied across the tile by torqueing opposing conical nuts threaded onto the tie bar ends to 3.5Nm. (See fig.2). This remedial action has been successful in preventing further cracks, and has been applied to other tiles subsequently installed in JET, notably the divertor tiles. Amending of the tie rods limits the tile bulk temperature to  $800^{\circ}\text{C}$ .

### **3. TILE FIXINGS AND INTEGRITY**

Various methods for Tile fixing have been used over the years varying from the complex arrangements of the Poloidal Limiter keyed spigot to a single bolt fixing that has been adopted as the standard. Generally captivated bolts and combinations of Alloy 718 disc springs are secured to the tile assembly with a threaded top hat insert (see fig.3). The alloy 600 or stainless steel 304/316 insert is screwed into a tapped counter-bore of typically M24 within the tile with the thread axis perpendicular to the fibre plane. The tapping of threads within CFC is feasible but the fibrous, anisotropic nature of the material leads to chipping of the threads. The insert is pinned against rotation by a pressed dowel that is tack welded to the insert during assembly. The single bolt fixing generally engages in an aluminium-bronze nut to avoid seizures. The nut is held captive by a number of different methods including open ‘c’-shaped cups with a tack welded locking strip or an integral clamping housing. In either case the aluminium bronze nut can be replaced if defective threads are experienced during installation.

Experience has shown that the quality and functionality of Alloy 718 disc springs can vary dramatically and significantly affect the long-term integrity of tile fixings. The specification for the supply of such items and acceptance criterion should be sufficiently detailed with the following salient points addressed. The precipitation hardening of the alloy 718 material should be carried out after the disc washers have been manufactured. The disc springs should then be scragged, this reduces the overall height by plastic deformation in a hydraulic press. Tensile stresses result on the upper side that counter act compressive stress caused by subsequent loadings and hence reduces stress peaks. Scragging therefore avoids further plastic deformation during later loading in service. Stringent acceptance tests are recommended consisting of disc spring stacks loaded at ambient and cycled to appropriate temperatures (500°C) to ascertain any significant reduction in pre-load deflection.

The 3000 plasma facing Tile Assemblies that were retorqued during the 1999 shutdown were predominately situated on the high field side and ceiling of the Torus. The original installation torque of the assemblies were 15Nm for the Dump Plate Tiles, Mushroom Tiles (Ceiling and upper outer wall) and Inner Wall cladding and 7Nm for the IWGL Tiles. Of the tiles that were removed for access reasons and sample retrieval purposes, undoing torque's as low as 3Nm were experienced for Inner Wall Cladding and 3.4Nm for Dump Plate Tiles [5].

The vast majority of Tile assembly fixations have a metal to metal bolted interface and there has been no observation of loosening of the fixation in operation. In contrast, the Dump Plate tiles on the ceiling of the machine include a graphite interface in the bolted assembly (see fig.4). A reduction in torque on the retaining bolt from 15 to 3 Nm after 4 years of operation equates to a relaxation of 0.2mm. The clamping load is further reduced with a graphite interface due to differential expansion, as the torque is applied at ambient whilst the vessel normally operates at 320°C [3].

An innovative vibration resistant female thread form has been used in the assembly of the Gas Box divertor modules, and the In-board Pellet Launcher and will be used in the new tile assemblies to be installed in the 2001 shutdown. In addition to a conventional 60° vee thread the proprietary Spirallock® thread form [2] features a 30° wedge shape ramp at the

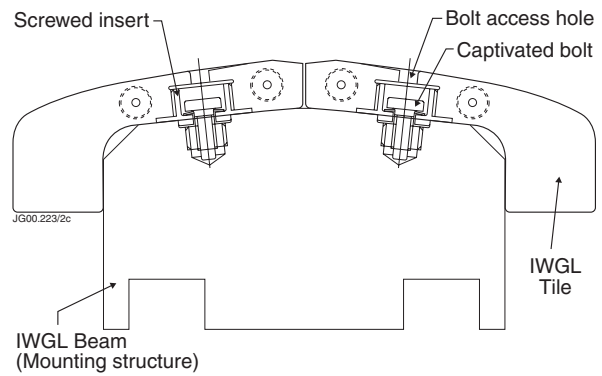


Fig.3: Cross-section through IWGL Tile showing typical single point fixing

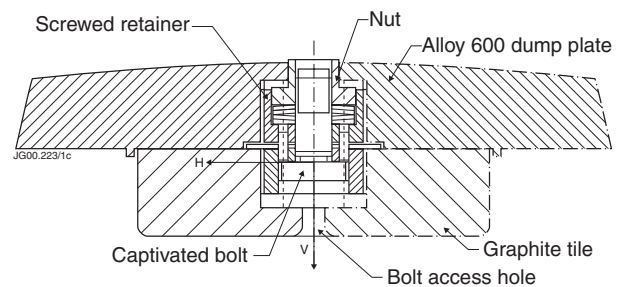


Fig.4: Cross-section through Dump Plate Tile showing alloy 600 to graphite bolted interface.

thread root. The radial clearances between the male and female threads in a standard arrangement allow sideways movement that is typically caused by vibration or transverse loading. This reduces the locking friction and leads ultimately to a reduction in torque and loose joints. Tests confirm that the wedge ramp provides a greater mechanical advantage that restricts bolt movement with no appreciable loss in clamping [4]. The 30° thread form also distributes the clamping load more evenly when compared to a standard thread where as much as 80% of the load is taken on the first two threads.

#### **4. COATINGS**

In the few occasions when high nickel alloys and stainless steels threaded components are mated, surface coatings have been used to avoid the seizure of these clean dry joints. Without these precautions, experience has shown that cold-welding of mating parts will inevitably occur at low torque. Titanium nitride was extensively used but this technique involved coatings of less than 1µm. Binding problems occasionally occurred due to thread and surface coating imperfections. Subsequently, 5µm copper and silver coatings have been electrolytically deposited onto the threaded section of bolts to provide a low friction bearing material. The application of the coating is limited to the nut mating thread to avoid exposure to the plasma. This is achieved by masking appropriate areas during the plating process or by coating the whole bolt and applying a stripping agent to the local area (i.e. the bolt head). An initial 1µm nickel coating prior to copper deposition improves surface adhesion. There is evidence that copper offers improve self-locking characteristics at elevated temperatures.

#### **5. CONCLUSION**

The effectiveness of copper and silver coatings have been well proven at JET. Copper coatings were first extensively used during the assembly of the Gas Box Divertor. There is evident to support the fact that such joints have a self-locking tendency under load at elevated temperatures. JET has never experienced any loosening of these systems under operational conditions.

During the 2001 shutdown tests of the Spirallock<sup>®</sup> threaded components that are the primary fixing method for the In-board Pellet Injector will ascertain their integrity. This will be the first time such assemblies have been assessed after approximately two years of operations. If, as anticipated no appreciable reduction in torque is seen then the vibration resistant female thread form will be adopted as the standard for future components.

In summary to ensure the prolonged integrity of plasma facing components, JET experience shows that the following points should be addressed.

- Tile material orientation (2D and 3D implications)
- Control of stresses and disruption forces on the tiles to minimise loading of the fixation (External support i.e. tie rods, halo currents isolation etc)

- The use of single point locking mechanisms that clamp metal to metal, with adequately specified disc springs.
- Innovative vibration resistant locking features like the Spirallock® thread form.
- Silver and copper coatings are effective in preventing seizures

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