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# Threaded connectors for sandwich pipes – Part 2: Optimisation of stress relief groove

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ABSTRACT

A concept for using snap-fit connectors in sandwich pipes is investigated numerically in two companion papers using a combination of 2D axisymmetric and 3D finite element models in Abaqus.

In the Part 1 paper, results of key parametric studies related to the installation analysis of sandwich pipes in deepwater are reported. The modification of the nib groove to include variable radii, the use of an elastomeric seal coupled with compressive pre-stress and an optimum resin-to-core ratio all proved to enhance the performance of the sandwich pipe snap-fit connectors. The influence of the interlayer adhesion configuration on the stress concentration experienced in the connector is also studied. Furthermore, a comparative study is performed to investigate the mechanical behaviour of the snap-fit connector concept in sandwich pipes and conventional pipe-in-pipe.

In the Part 2 paper, an optimisation study is carried out for the stress relief groove (SRG) in the pin of the snap-fit connector. A combined parameter is proposed to capture the relationship between the investigated geometric properties and the stress concentration factor at the SRG. It is established that the fillet radius could indeed be used to offset the drop in performance associated with increasing the SRG depth while improving the fatigue characteristics of the connector threads.

## 1. Introduction

Threaded and coupled (T&C) connectors have been utilised in offshore oil pipelines with a good track record and serve economically well especially in shallow waters. They can be viewed as an alternative joining method for pipelines and risers in deepwater, where increased wall thickness and use of high strength steels could make welding a less favourable option.

It is well known that seal integrity and uniform stress distribution along the thread roots remain key challenges for threaded connectors especially when placed under severe bending loads [1]. There exist a wide variety of “qualified” improvements to the conventional T&C connector, mainly driven by enhanced mechanical performance for its use in risers, drill pipes and tendons. These improvements range from local to global geometrical modifications and a few are discussed in this paper. All improved designs seek to tackle a number of operational challenges depending on the joint requirements. The reduction of high local stresses and a more uniform stress distribution along the joint remain design priorities which when optimised lead to a better fatigue resistant connection.

This paper aims to identify the fatigue critical regions for a snap-fitted sandwich pipe and explore modifications to reduce the stress concentration in such regions. The relationship between the stress concentration at these regions and the connection's mechanical/geometrical properties is investigated for typical installation loads (bending, external pressure and axial loading). The formulation of optimisation parameters to predict connection performance via parametric finite element analysis in Abaqus (Dassault Systèmes 2014) is also studied, in particular geometrical properties of the nib groove (considered in the Part 1 paper) and stress relief groove (considered in the present Part 2 paper). A better understanding of the added complexities to the snap-fit connector for its utilization in sandwich pipes is gained from the results from this study. As a complex multiaxial stress distribution is expected over the connection, the maximum principal stress is used.

## 2. Trends in connector improvement

A large variety of patented improvements to threaded and coupled pipe connectors follows two general trends, namely: modifications to the joint global geometry [2,3], and modifications to the thread profile, [4–7].

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Under installation loads, a conventional threaded connection will have peak stresses located at the root of the first engaged thread (FET) of the pin and last engaged thread (LET) of the box [8].

Local stiffness reduction to enhance uniform loading in the joint has been utilised in most solutions with numerical and experimental tests documented to verify this. This approach is guided by easing the transfer of load between joint components at identified regions of local high stresses. This approach was utilised in [9] by applying a groove at the outer surface of the coupler box which is radially aligned with the LET of the pin. This would lead to a reduction in stiffness around that section, thus making it easier to deform elastically and transfer load more uniformly across the joint length. Longer engaged threads were proposed by both [2] and [3] with modifications to include thread run-out allowing for partial engagement of threads. This allows for some level of stress redistribution around the LET and as thus reduces the high local stresses that would normally have occurred.

It is well known that modifying the thread profile (especially at the root), could lead to an optimal design to reduce unwanted high stress regions in the connection. A conventional thread profile is defined by its height, flank angle, root groove finishing, pitch, load flank interference and fabrication tolerances, ASME B1.20.1 [10]; leading to a pool of variables to combine with the aim of arriving at an optimal design. This is no mean feat as some designs although showing an improvement in fatigue properties for the connector, require unattainable fabrication tolerances at that scale [11]. This creates a hurdle for this approach from an economic and technical point of view.

Nevertheless, significant improvements have been made to standard thread profiles. Take for instance, an early modification in Ref. [12] which adopted a larger radii and stress relief groove at the root coupled with a modified pin profile pitch to improve load distribution via radial interference. In [2], the approach was taken of designing with a zero degree load flank and increased root radii with the goal of significantly reducing the radial component which contributes to pin-box thread separation. In [13], an improved fatigue connector was patented with load flanks having rounded corners while also designing the thread profile with a negative load flank which through research in Ref. [14] showed improved resistance to plastic yielding, galling and increased tensile, bending and external pressure capacity. Modifications in Ref. [7] took the approach of grooving the FET and LET of a buttress type thread in aim of reducing the stiffness and creating multiple stress zones which in turn improves load distribution around the FET and LET region. In [15], modified design was proposed by using two-step stabbing flanks for the threads in aim of improving pin insertion and galling resistance. In [1], a threaded profile was proposed, in which the gap between the loading and stabbing flanks was closed, increased the root radii, increased the chamfer angle on the stabbing flank and moved surface contact from the pin thread root. The resulting profile was reported to be able to isolate the effects of fretting from the effects of fatigue loading.

Another proven approach to improving connector performance is the inclusion of stress relief features in the joint geometry. According to API 7-1 (2006), stress relief features can be described as “a modification performed on rotary shouldered connections by removing the unengaged threads on the pin or box to make the joint more flexible and to reduce the likelihood of fatigue-cracking in highly stressed areas”. The two most common features are: the stress relief groove (SRG) and the bore back (BB) as shown in Fig. 1. Stress relief features will cause a slight reduction in the tensile strength of the pin and the section modulus of the connection. However, under most conditions this reduction in cross-sectional area is more than offset by the improvement of the connector under fatigue loading, hence its acknowledged advantage [16]. In other words, this leads to a reduction in stiffness at the groove region and as such is elastically deformed preferably to lower the stress concentration that normally occurs in the LET. In [8,17], it was revealed that the use of SRG and BB in a standard NC46 and NC50 connector indeed had advantages in reducing the stress concentration in T&C connector under axial, bending and torsion loads.

No doubt the adaptation of stress relief grooves into the design of T &C connectors has been welcomed and its effectiveness in prolonging connector life established [18, 19]. In [20], conclusions are drawn via experimental fatigue testing under service conditions that an optimal stress reduction can be achieved in an NC50 connection with a relief groove width of approximately 1-inch. Ref. [21] also agreed with this optimal width by carrying out a parametric study on a 5-1/2 F.H connector, also concluding that the engagement of a partial box thread rather than a full thread with the LET of the pin has a significant advantage by lowering the stress in that section of the pin.

It should be emphasized at this point that although T&C connector design is properly standardised for drill pipes and to some extent for risers, when it comes to its application for oil and gas pipelines, proprietary joint types rule the market space. Some would argue that this is due to the uniqueness of multiphase oil and gas transport and flow conditions while some would blame it on a weightier industry confidence on welding as a preferred joining method for pipelines. This on the other hand has helped forge a new business line for joint designers who seek to develop new and modified systems to make economic profit. At the moment, threaded connectors for flowlines are certified by ISO 21329 (2004) and follow strict adherence to operational health and safety.

## 3. Stress relief groove

It is well known from standards [20] and numerical analysis [8,17,18,21] that the stress relief groove and bore back represent an effective modification to threaded line pipe joints leading to improved fatigue performance and prolonged connector life. The pathway to this solution involves reducing the maximum SCF in the connector which is generally known to be at the LET of the pin threads. The influence of this solution at the critical LET of the pin can be seen in Fig. 6a of the Part 1 paper; this was also adopted in the snap-fit connector design for sandwich pipes. For elastic analysis, the truncation height for the connector threads had no significant effect on the SCF at the thread roots as the SCF was calculated as a function of the root diameter.

The stress relief groove design for an 8-inch threaded pipe is shown in Fig. 2a. To achieve geometric convergence some dimensions were made consistent with (ASME B1.20.12013) standard dimensions or derived as function of such dimensions. The essential geometric parameters describing the stress relief groove to be used in this study are shown in Fig. 2b.

Parameter description and expression is shown in Table 1. As is seen, some parameters are made functions of others. An elastic material model was used with properties of API X65 according to [22]. The material was modelled as elastic-perfectly plastic. The material's yield stress was set at 448 MPa, elastic modulus at 207 GPa and Poisson ratio of 0.3. As the study focused mainly on the LET and SRG, only six fully engaged threads were used (Fig. 3a) and the axial load scaled down to 30 MPa. Makeup was modelled by using a simple tie constraint at the inner abutment face which proved sufficient as the load applied was not above the jump-out strength of the connector as estimated by Ref. [23]. The pin end was fixed while the axial load was applied at the box end with contact properties defined about the pin and box threads using a coefficient of friction (COF) of 0.1. In elastic analysis, it has been proven that the COF doesn't significantly affect the stress and load distribution patterns within the connector [21] but being a property that defines surface forces, it was showed in [11] that the COF has somewhat of an inverse relationship with thread opening, meaning that using an appropriate COF in modelling threaded connectors is necessary. Again the maximum principal stress (axial) is used as the measure for reported stress in this study which is complaint as studied by Ref. [24] and is in concordance with the direction of loading.