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# Premium & Semi-premium Connections Design Optimization for Varied Drilling-with-Casing Applications

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## Abstract

As high resistance to fatigue loading together with high overtorque and compression capacities are at the top of a list of required features for connections to be used in new drilling and completion techniques such as casing drilling, then special connections with enhanced performance need to be developed. On the other hand, a cost-effective solution should be chosen to balance the performance when considering low-demanding shallow wells for which sophisticated premium connections could be uneconomical.

This paper describes the development and evaluation of premium and semi-premium connections for tubing/casing which were developed to stand cyclic loads and reach an extended number of cycles under such conditions. The development process of an integral connection for casing sizes targetting very demanding applications comprised Finite Element Analysis (FEA) and Full Scale Fatigue Test (FSFT) showing Stress Concentration Factors (SCF) lower than 2. In addition, during the development of the semi-premium connection to cover less demanding applications, some of these techniques were used to optimize the results until getting SCF lower than 3, good enough when low doglegs are present. The results of the tests are plotted in S-N (Alternating Stress vs Number of cycles to failure) curve with a standard curve as a reference.

As per the results, both types of connections achieved the objective set at the beginning of the development process now being suitable alternatives for low and high demanding drilling/completion operations.

## Introduction

The use of OCTG connections for drilling appeared some time ago as a possibility to reduce costs by eliminating tripping in and out of drill pipes, and moreover to solve some instability problems [1,2] that normally occur while drilling conventionally. However, this new technology brought the necessity of improving the fatigue resistanc of OCTG connections. Traditionally, due to the standard drilling and completion techniques, all OCTG connections (API and proprietary) were designed to stand static loads while they only needed to be rotated for complex operations such as directional, horizontal and extended reach wells.

Casing Drilling, so far, has been mainly applied on low demanding vertical wells for which in almost all the cases API connections were used sometimes with some modifications to improve torque capacity. For these applications where the application is pushed by an important reduction in cost, a semi-premium connection with high fatigue resistance, low sealability requirements, extra torque and compression has been developed. The tighter tolerances of a semi-premium connections allows for a more stable, fatigue-wise behavior.

Nevertheless, as the current horizon of this drilling technique is being moved towards more demanding and critical applications [3,4] such as horizontal/ deviated oil/gas wells, and also offshore oil/gas wells where most of the wells are drilled directionally, new types of connections need to fill the vacuum left by the standard premium connections. The driver requirements for these connections are reliability, sealabity, high overtorque capacity and ultra-high fatigue resistance as the stresses produced by high bending and vibrations while rotating could reduce the life of the connections.

In this paper, the development of a cost-effective semi-premium connection and an ultra-high fatigue resistance connection is described. The Finite Element Analyses and the results of Full Scale tests are included as well.

## Connection for Casing Drilling – Considerations

As it has been mentioned before, standard OCTG casing connections were designed to withstand only the typical static loads, that either alone or combined, affect the string: tension/compression, internal/external pressure and bending. Moreover, the torque required for most applications –with the exception of horizontal and extended reach wells, are normally low.

On the contrary, for Casing Drilling some other critical issues, which become even more critical for drilling directional and deviated wells, should be considered in advance for a successful job:

- Wear protection
- High torque & compression (casing OD larger than drill pipe)
- High fatigue resistance
- Cost effectiveness

Wear protection is being handled by means of centralizers [5] or other hardened surfaces located close to the pipe end in order to avoid damage on the connection.

The high torque and compression requirements are necessary to overcome the resistance of the drag produced by the greater diameters of the casing, compared to drill pipes, and the weight of the string. Higher torque values and compression resistance are achieved by appropriate designs including robust torque shoulders, thread interference and reduced gaps between mating threads or flank-to-flank thread design.

Fatigue resistance is a very important issue for drilling casing and perhaps the most difficult one to tackle.

Having these conditions in mind, the questions to be analyzed are "What cyclic loads are to be seen during the drilling operation? What type of connection is needed? Does this well complexity justify a premium connection?" As some tips concerning wear protection and torque capacity have already been mentioned we will focus our attention on fatigue behavior and on balanced alternatives from cost perspective.

**Fatigue response of OCTG connections**

Fatigue is a complex process that affects mechanical components that are subjected to cyclic loads. Fatigue failure is not a sudden crack, instead it involves different development phases until the failure of the component becomes evident, being this failure produced at stress levels far below the static elastic limit of the material. The number of loading cycles to reach the failure of the component is proportionally inverse to the stress range applied on it, i.e. the difference between the maximum and the minimum stresses. In steel, however, there is a low stress limit under which cracks do not propagate. In addition to the above statement another important factor is the mean stress applied on the connection which could reduce the fatigue life significantly as it becomes higher. Consequently a better fatigue response, i.e. a much longer life, can be obtained by reducing the mean stress.

When subjected to cyclic loading, ordinary OCTG connections are weaker than tough drill pipe connectors which are meant for working at alternating stresses. The fatigue failure of threaded connections is located in the area with the highest Stress Concentration Factor (SCF), the latter defined as

$$SCF = \Delta\sigma_1 / \Delta\sigma_m$$

where,

$\Delta\sigma_1$: Change on the maximum first principal stress

$\Delta\sigma_m$: Absolute value of change in the average stress applied to the pipe wall

The location of the SCF can be estimated with Finite Element Analyis (FEA) through which it is also possible to obtain a numerical value of the SCF for a specific load spectra applied on the connection. The FEA shows that for T&C connections the most critical area for fatigue is within the vanishing threads somewhere in the middle of the incomplete thread zone. For standard premium OCTG connections with the loads expected in drilling with casing applications the SCF is normally higher than 2.0 [6], however from a fatigue perspective it is desirable that the SCF value be as low as possible.

The response of a threaded connection to fatigue loads –in a similar way as any other mechanical device, can be plotted in a S-N curve. One curve that is normally used to evaluate the fatigue response of this type of connections is the Class B curve (design and mean) per BS7608 [7] which represents the behavior of a plain material free from welding as rolled, ground or machined smooth, while for drill pipes other curves are used which are shown in API RP 7G [8].

The alternating stress for a Casign Drilling operation is produced by the dogleg of the string while the same is being rotated. The mean stress is produced by the axial loads applied on the string. Consequently, a balance between the axial load (mean stress) and the maximum dogleg that can be applied while rotating needs to be achieved for a longer life.

**Fit-for-purpose alternatives**

The development of a semi-premium connection was launched aiming to get alternatives for low demanding wells but with a good enough fatigue response. The basic requirements included threaded and coupled design (T&C), with no metal seal, and no swaging.

On the contrary, for the connection with ultra-high fatigue resistance the target was to obtain a tough connection with very low SCF and excellent sealability. Therefore the result is an integral, upset connection with two shoulders and metal-to-metal seal. The manufacturing of these connections involves additional processes such us upsetting and its by-processes, and turning the metal seal.

## Connection development program

Tenaris launched a development program to provide different alternatives of connections for Casing Drilling. As results of this program, different options were evaluated and tested in full scale from a semi-premium, with enhanced fatigue lives when compared to API modified connections [5], to a premium fit-for-purpose connection with a enhanced fatigue life which at least compares against the Class B curve.

For the semi-premium concept a T&C design [Figure 1] was chosen as T&C API connections had been used for similar low demanding applications. The main features of this design include tighter tolerance range than API connections, a robust torque shoulder in the coupling that allows for stable make-ups and extra torque capacity with controlled stresses along the threaded area, and a robust thread design.

For the premium connection the decision went to a tough casing design on an upset joint [Figure 2] based on a proven design for tubing drilling and workstring applications [9]. Similarly, two robust shoulders were included that allow for enough pre-stress levels while having an ovetorque capability that assures that no damage is being produced on the connection as a result of such pre-stress.

The evaluation of different alternatives included FEA, FST and make-&-break. In addition, magnetic particle inspections (MPI) were carried out after the fatigue tests on the unfailed specimens to check for the presence of cracks.

**Finite Element Analysis**

Finite Element Analyses were performed to evaluate fatigue response. These analyses covered 7” 32ppf L80 Tenaris PJD Special Clearance connection and a standard threaded & coupled connection for comparison purpose. Connections were modeled in extreme configurations of thread and seal, and simulating two stress levels with a mean stress of 30% the minimum API yield strength.

The FEA procedure is described in detail in [10]. A special version of the ADINA code [11] is used. This version incorporates the QMITC element [12-14], which is effective and reliable for the analysis of OCTG connections, as shown in [14, 15]. Small displacements and small strains are considered in the model. An elasto-plastic material model and von Mises yield criterion [16] are adopted. We use a bilinear model with isotropic hardening,

$$\sigma_y = 80\ ksi = 56.26\ kg / mm^2$$
$$E = 29900\ ksi = 21000\ kg / mm^2$$
$$E_t = 299\ ksi = 210\ kg / mm^2$$
$$\nu = 0.3$$

Non-linear contact conditions are handled with a Lagrange multiplier contact algorithm [17].

In all the cases, the make-up torque value was increased to a higher value than that used for casing running to assure a good pre-stress in the connection, aiming to get both shoulders permanently closed during the loading cycle.

The control points where located in the most sensitive areas of the connection [Figure 3]. The SCF map of Figure 4 and the graphic of results of Figure 5 and 6 show that the highest stresses for different alternating loads are produced at either the the first or second threads of the pin or the box depending on the stress applied. This is different from what it is normally observed on T&C connections where permanently the highest SCFs are located within the last imperfect threads of the pin member [Figures 7, 8].

As can be seen in Figures 4, 5 and 6 the SCF obtained on the Tenaris PJD do not exceed 2.0 and even in some cases is close to 1.0 which means that the connection achieves the target of design, that is getting a SCF lower than 2.

**Fatigue resistance tests**

The connections that underwent the full scale testing program, Tenaris PJD and semi-premium joints, were manufactured on 7” 32ppf L80. The samples were manufactured according to standard manufacturing procedures, however the integral upset ones were manufactured on a coupling stocks [Figure 9] with the upset ends turned aiming to reduce any possible imperfection in order to put the connections in the worst condition.

The full scale tests were performed at Stress Engineering Services (Houston, TX) on three samples of the T&C and other three samples of the Tenaris PJD connection using a resonant fatigue rig [Figure 10]. The tests were planned to stop when the connections and/or the pipe leaked, for that reason to collect the leakage the connections and the pipes were covered with a flexible boot leak trap device [Figure 11].

Both connections were tested at the same stress levels as is normally recommended for this application [11], but the mean stress levels were slightly different to put the upset end in a worst condition; the run-out limit was set at 12 million cycles in case failure does not occur. The stress levels were set at 29ksi (200MPa), 21.8ksi (150MPa) and 14.5ksi (100MPa), in addition the upset connection tested at 14.5ksi was furtherly tested up to 39.1ksi (270MPa) to produce the failure. These values were chosen to simulate bending conditions [10], of 19°/100ft, 14.3°/100ft, 9.5°/100ft and 25.6°/100ft, respectively with a mean tension load of 236.5kips for the Tenaris PJD and 220kips for the T&C.

**Fatigue test results**

The threaded and coupled connections behaved very well achieving satisfactory results when compared with the Class B curve [Figure 12] providing an experimental SCF of 1.3 with a probability of survival of 95%. According to the results this connection could drill with 9.5°/100ft for more than eighty days with a tension load of 220kips.

Concerning the integral upset connections, all the failures occurred on the pipe body, actually on the transition area located away from the connection [Figure 9]. The first connection tested achieved 868,000 cycles with a failure at the tong marks [Figure 13], and it was replaced by a spare specimen which had the tong marks ground out. This spare specimen achieved more than 3 million cycles with a failure produced in the transition area. This means that the 7 inches connection can drill during twenty days at 100 rpm with a bending of 19°/100ft and a tensile load of 236.5kips. These results corroborated the excellent performance already shown for the tubing sizes [9]. The experimental SCF for the upset connections is 0.9 with a probability of survival of 95%.

The results of both connections are plotted against the minimum requirements of API RP 7G for grades E-75 and X-

95 in Figure 14. Since these curves are plotted up to one million cycles extrapolations of these curves up to a hundred million cycles were needed and the minimum endurance limits were chosen for compressively loaded drill pipes in E-75 and X-95 22ksi and 23.1ksi according to Table 22 of API RP 7G.

The results are also plotted with the Class B curves (mean and design) where also is shown for reference the endurance limit of 12ksi (82MPa) for K55 API Buttress connections [Figure 12]. The results are comparable since the fatigue response is related to the ultimate strength and not to the yield strength.

**Magnetic particle inspection**

After the fatigue tests, the connections were broken out inspected at Stress Engineering Services with magnetic particles. The inspection showed that for the upset connections the cracks developed at the transition area or at the tong marks for first upset connection [Figure 13] and on the transition for the others [Figure 15]. No cracks were found on threads and seals, and the visual inspection confirmed that no damage appears on threads and seals in spite of high make-up torques [Figure 16, 17]

Concerning the T&C semi-premium connection, no cracks were found in the threaded area.

## Discussion

The results showed that the connections satisfactorily achieved the requirements established at the beginning of the development program, that is, for the semi-premium connection the purpose was to obtain a better behavior than the API connections currently used for drilling casing applications. Concerning the premium connection, it was demonstrated that this design satisfies the objectives as in all the cases, with the exception of the failure due to tong marks, fatigue lives exceeded the Class B mean curve without showing any failure on the connections (failures located on the transition areas or tong marks). For the connection tested at 14.5ksi which was stopped at 13 million cycles and re-tested at 36.2ksi achieving more than 770 thousands cycles, the cumulative damage on the pipe permits estimate fatigue life of 50 million cycles at 14.5ksi (9.5°/100ft) or 1.04 million at 39.1ksi (26.5°/100ft) with no damage on the connection.

Additionally, the T&C connections were also overtorqued to 160% of the nominal value while the upset connections were overtorqued up to 290% of the optimum torque which demonstrates the overtorque capacity of these connections; in particular the behavior of the upset connection repeated the same performance achieved by the tubing design [9].

## Conclusions

Based on this experience the following conclusions can be made:

- The Tenaris PJD premium connection demonstrated a ultra-high fatigue resistance without showing any failure on the connection.
- The bending angles at which the connections were tested make them suitable for deviated wells, in particular the upset connections which also allow for very high angles with a very important life expectancy.
- The semi-premium connection presents a very good balance between performance and cost which makes it appropriate for less demanding wells with no sealability requirements.

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Figure 1 – Semi-Premium T&C Connection

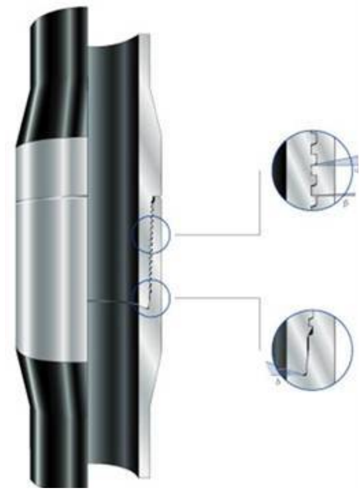

Figure 2 - Integral Premium Connection

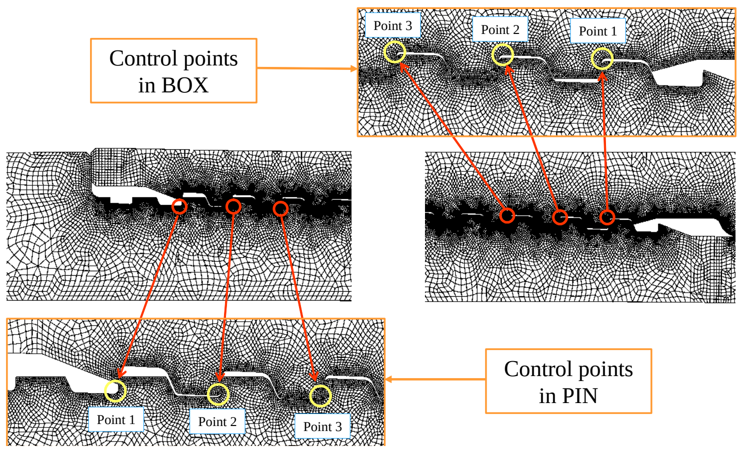


Figure 3 – Control points for FEA

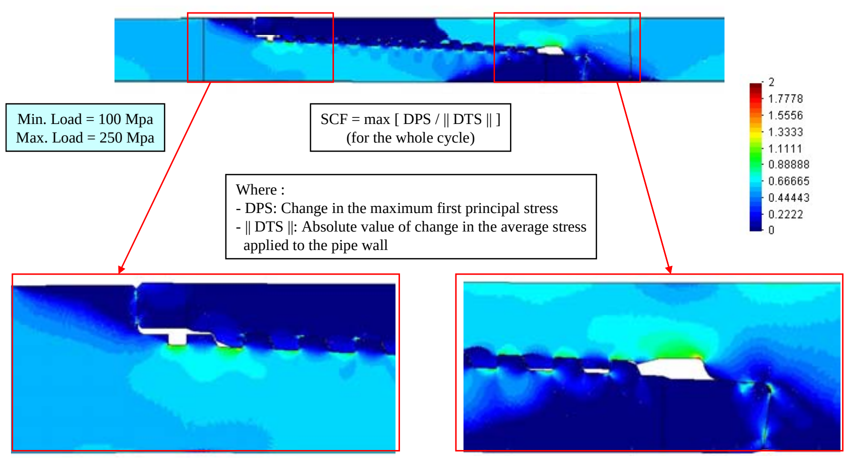


Figure 4 – SCF map of the Tenaris PJD 7”32# Spec. Clearance

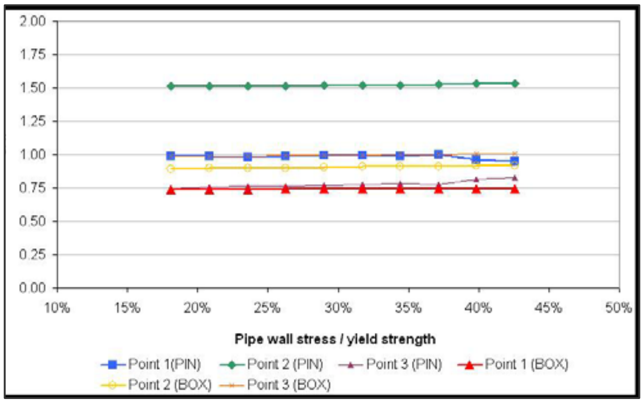


Figure 5 – SCF evaluation along loading cycle (Maximum Stress range)

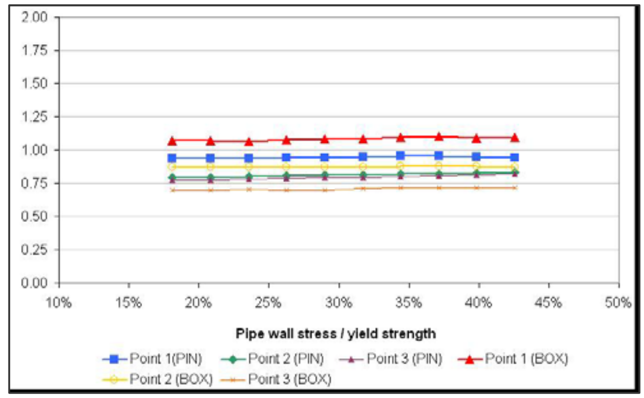


Figure 6 – SCF evaluation along loading cycle (Minimum Stress range)

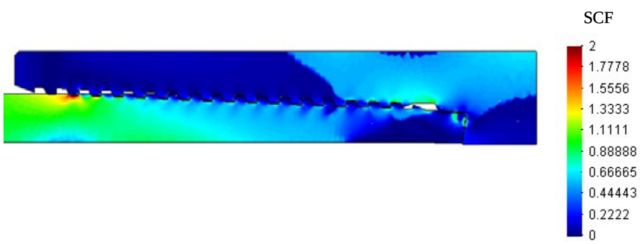


Figure 7 – SCF distribution on typical T&C connection

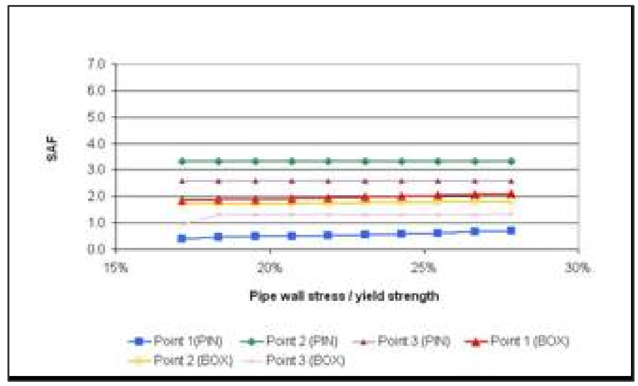


Figure 8 – SCF evaluation along laoding cycle on typical T&C connection

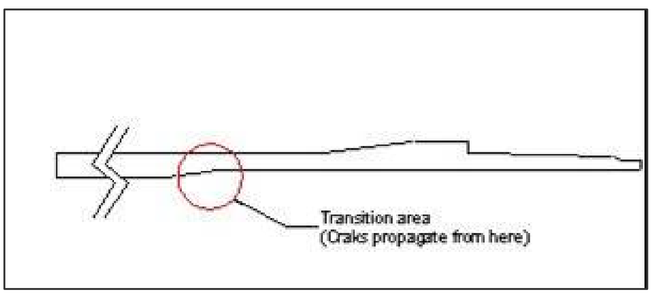


Figure 9 – Sketch of tested Tenaris PJD connection

Figure 10 - Resonant fatigue rig set up with an integral upset premium joint (photo by courtesy of Stress Engineering Services Inc.)

Figure 11 – Leak trap device over the semi-premium joint set up at the resonant rig
(photo by courtesy of Stress Engineering Services Inc.)

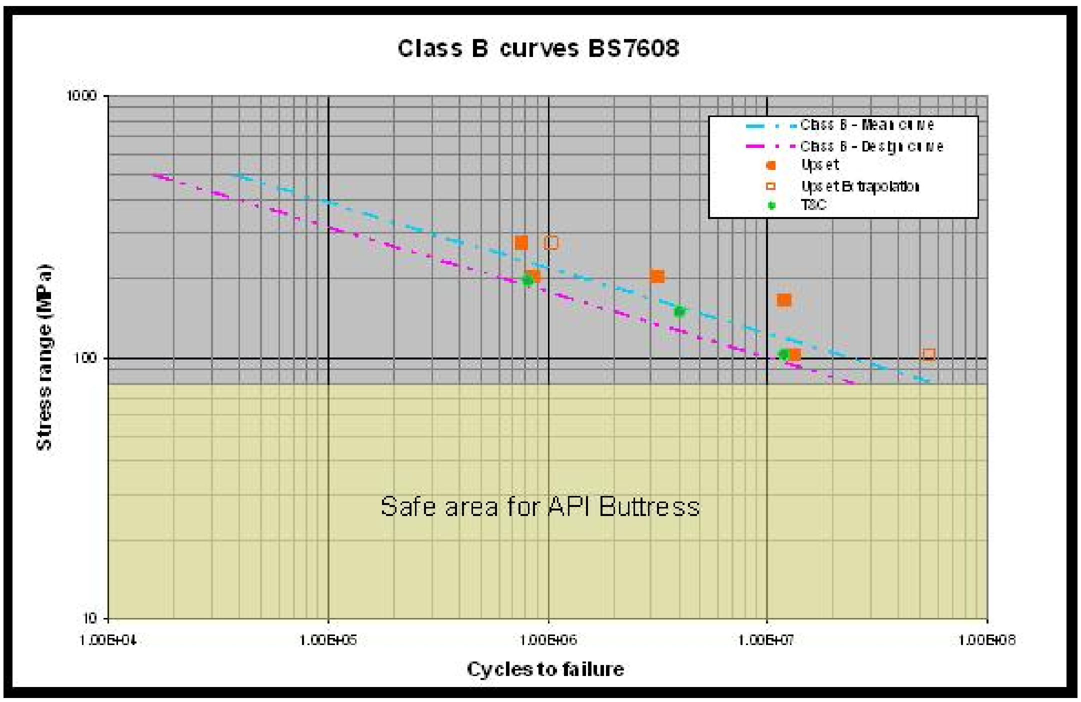


Figure 12 – Testing data plotted against Class B curves

Figure 13 - Crack marks shown by magnetic particles inspection on tong marks

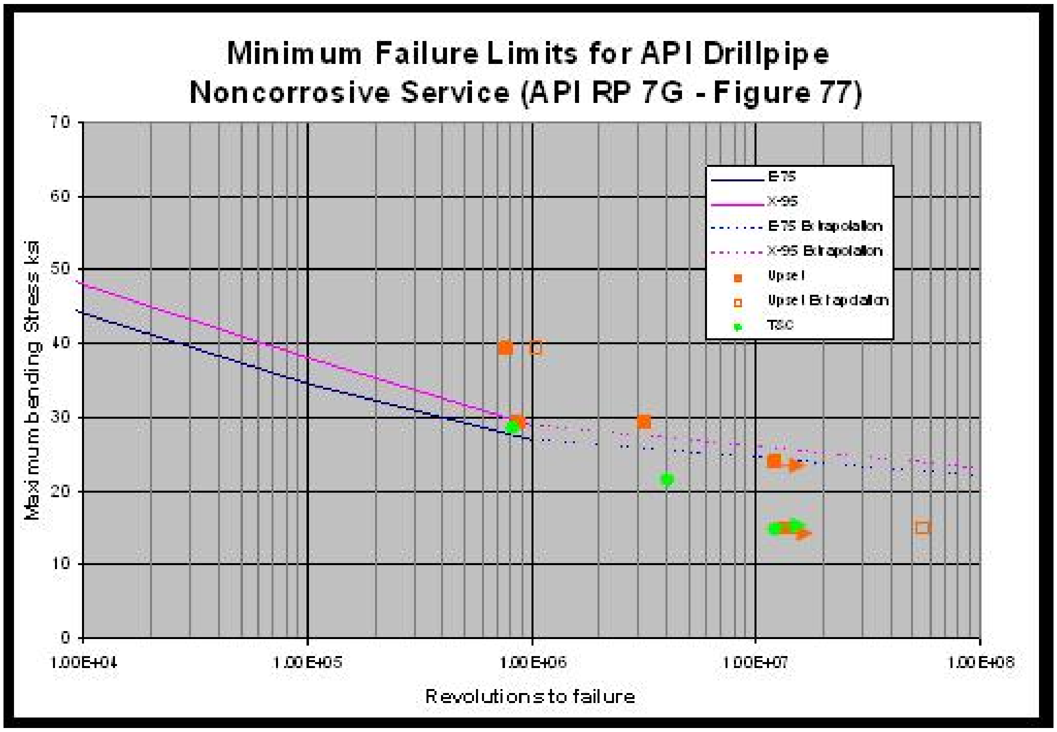


Figure 14 – Testing data plotted against API RP7G Figure 77

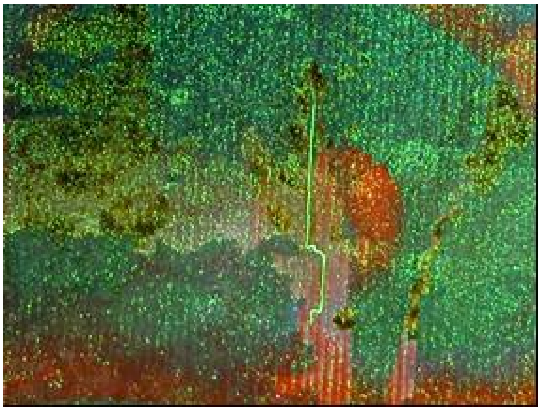

Figure 15 - Crack marks shown by magnetic particles inspection on transition area

Figure 16 – Visual inspection on Tenaris PJD pin side after after fatigue test

Figure 17 – Visual inspection on Tenaris PJD box side after fatigue test