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High-strength Line Pipes with Enhanced Deformability

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Strain-based designed (SBD) pipelines have to exhibit both a high strength level and an enhanced deformability, a combination which is not always obtained in the current productions, especially for ultra-high grade pipes (e.g. X80 and higher). This paper focuses on the one hand on the results of finite element analysis, which allows the identification of adequate tensile pipe properties, and on the other hand on the effect of microstructure on cold deformability and work-hardening of high-strength steel for line pipes to be subjected to displacement applied conditions.

INTRODUCTION

The increasing gas demand expected in incoming years will be satisfied by realizing a number of worldwide high-pressure gas transmission lines which should face challenging environmental conditions such as permafrost, landside and earthquake. To guarantee economic and safe gas delivery to the market, such pipelines have to exhibit both a high strength level and an enhanced deformability, a combination which is not always obtained in the current productions, especially for ultra-high grade pipes (e.g. X80 and higher).

In this work, first of all, a Finite Element (FE) analysis has been carried out in order to identify adequate tensile pipe properties for strain-based design (SBE) applications of high-strength pipelines. The influence of tensile parameters, in particular the strain hardening exponent, on the pipe deformability response has been investigated by means of an FE model, which reproduces a pure bending condition with internal pressure.

The properties have to be achieved during pipe production by a proper metallurgical design. For this purpose the effect of microstructure on cold deformability and work-hardening of high-strength steel for linepipes has then been investigated. Both experimental data on laboratory steels and analytical results by an iso-working model were exploited to identify the microstructural features which allow the achievement of target mechanical properties in terms of $Rt_{0.5}/Rm$ and work hardening rate.

FINITE ELEMENT ANALYSIS

Model Description

The FE analysis has been performed by using the commercial software MSC.Marc© implementing a solid model. Table 1 reports the 2 different pipe geometries that were taken into account.

By exploiting geometry and loading symmetry, only one-fourth of a pipe has been modelled for simulation, and appropriate boundary conditions have been applied.

The element type used is the 3-dimensional arbitrary distorted brick which is available in the Marc© database. In order to reduce calculation time, different axial element sizes have been used to mesh the pipe.

	GEOMETRY 1	GEOMETRY 2
Outside diameter (D)	1219.2 mm	323.85 mm
Wall thickness (t)	19.8 mm	14.5 mm
D/t	61.6	22.3
Pipe length (L)	8000 mm	1000 mm
L/D	6.6	6.2

Table 1 FE model's main characteristics

The following discretization has been implemented:

• longitudinal element size equal to 12.5 mm (for an extension of 500 mm) close to the expected bulging position;

• longitudinal element size equal to 25 mm (for an extension of 500 mm) in an intermediate pipe region;

• longitudinal element size equal to 50 mm in the remaining part.

In the circumferential direction, a number of elements (out of 44) has been used. Four elements have been used through the wall thickness for a 1000-mm length from the pipe end, while the remaining part has been modelled by implementing only 2 elements, having previously verified that this array is accurate enough for reproducing the pipe bending behavior.

The aim of the FE analysis performed is to study the influence of characteristic material parameters (such the strain hardening exponent) on the limit strain which the structure can bear before the occurrence of failure when subjected to internal pressure plus bending. In particular a condition of pure bending (i.e. plane stress) has been accounted for by imposing a rotation of pipe end sections. This has been achieved by using the touching contact feature which allows for the ovalisation of a pipe cross-section.

The pure bending condition is then achieved by imposing the following displacement conditions onto the contact plane, bearing in mind the model symmetry:

• One plane is forced to rotate around the pipe cross-section symmetry line, which also represents the neutral axis since pure bending is applied.

• Rotations of the other plane are not allowed while the plane is free to translate along the longitudinal pipe direction, just to permit pipe shortening in order to avoid undesired axial stresses.

Since pressurized pipes have been taken into account, internal pressure has been applied before the bending deformation and maintained constant during the whole simulation. On the other hand, no pressure has been applied on the pipe end caps.

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KEY WORDS: Line pipe, strength, deformability, finite element analysis, microstructure.