**ABSTRACT**

The present paper presents results of a perennial study on the effect of thermal treatment on collapse strength of cold formed pipes, for instance those following the UOE production route. For many years, it has been known that thermal treatment, as it is encountered during the cryogenic cycle of pipe coating processes, may compensate the reduction of effective yield strength owing to cold plastic deformation. The underlying investigation aimed at a systematic analysis of this effect. In particular, it will be shown that thermal treatment manifests itself positively with respect to collapse resistance, leading to improved collapse pressures. Based on a thorough understanding of the phenomenon, a concept was developed, which is capable of monitoring the positive effect of thermal treatment by appropriate laboratory simulations on compression specimens. This will make it possible to demonstrate improved collapse pressures under the conditions of serial production, based on simulations of thermal treatment performed on samples rather than relying upon full-scale testing.

**KEY WORDS:** Collapse resistance; thermal treatment; plastic collapse; compression strength; simulation of thermal treatment; quality management

**INTRODUCTION**

Advances in technologies for exploration and production do allow previously uneconomic hydrocarbon reserves to be accessed. It is for this reason that future pipelines are being planned to run across difficult environments (Martin, 2006), for instance ultra deep water. This situation naturally entails demanding material and line pipe design issues to be resolved.

Line pipe intended for ultra-deep water application predominantly has to be designed with regard to ambient hydraulic pressure action in order to safely withstand plastic collapse. This is due to the fact that off-shore line pipe is not subjected to internal pressure until the pipe string will have been completely installed on the seabed. Design against external pressure is very much different to design against pressure containment. In the first case, stability is the driving parameter governing success or failure and, thus, it is compressive yield strength in circumferential direction rather than tensile yield strength that is to be considered. Hence, the minimum wall thickness requirement is now linked to external pressure. In addition to compressive yield strength, diameter to thickness (D/t) ratio, roundness of cross section (ovality), residual stresses and pipe stress-strain behavior do play a major role.

Cold forming operations according to UOE pipe manufacture and subsequent anti-corrosion coating may exert significant effect on characteristic stress-strain behavior of parent material. For instance, the last cold forming operation within the UOE pipe production route, the so-called expansion, would effectuate some reduction of collapse strength if the pipe were not coated. This phenomenon is to be attributed to the Bauschinger effect (1886), which signifies a reduction of yield strength whenever there is a load reversal after previous plastic straining. Today, off-shore line pipe is generally treated with anti-corrosion coating. It is for this particular reason that, generally, this effect is not apparent any more. Thermal ageing raises compressive yield strength and, thus, compensates the drop of compressive yield strength caused by cold expansion.

From the above, it appears that it is reasonable to account for all relevant production steps in line pipe design. The present paper addresses this issue, notably in the context of thermal treatment of line pipe such as encountered in pipe coating processes. In particular, it will be shown that the adverse effect of cold plastic deformation on the yield strength of UOE pipes is not accounted for, hence, on their collapse strength can be conveniently compensated for by thermal ageing at appropriate temperatures (200º C up to 220º C). This effect has been analyzed and documented in many articles, for instance in Graef et al. (1996), Al-Sharif and Preston (1996), DeGeer and Zimmermann (2004) and more recently in Tsuru et al. (2006) and Liessem et al. (2006).

Standards intended for off-shore design do neither account for the positive effect of thermal treatment nor do they refer to compressive yield strength although it would be more reasonable from a physical point of view. Rather, these resort to tensile yield strength only. For example, DNV-OS-F101 (2000) advises to determine a fabrication factor $α_{b,c}$ for pipes manufactured within a fabrication process that introduces cold deformation (giving different strength in tension and compression). The fabrication factor is then to be applied to the characteristic (tensile) yield stress. It describes the reduction of compressive yield strength relative to specified yield strength. Unless other information exists $α_{b,c}$ shall be taken as 0.85 for UOE pipes. However, having in mind the positive effect of thermal treatment,