Physical metallurgy of high-strength, low-alloy line-pipe and pipe-fitting steels

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The effect of the characteristics of plate mills for production of plate and U–O–E pipe, and of continuous mills for production of strip and spiral pipe, is discussed in relation to ferrite–pearlite and two-phase steels. The influence of the cold work applied during pipemaking and expansion on the behaviour of each type of steel is considered, and the role of microalloying elements, individually and in combination, is discussed. The structure and properties achievable in normalized steel for pipe fittings are reviewed, and the effect of microalloys on weld properties is summarized. *MT/985*

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Unlike most other structures, line pipe (except when quenched and tempered in pipe form) is used in the cold-worked condition and the process of cold working the steel plate during pipe forming and expansion, when this is carried out, plays a critical part in determining the properties of the pipe. In some steels it lowers the strength of the pipe compared with the plate, and in others it increases the strength; in almost all steels it reduces the steel toughness. In pipe forming, the inner layers of the plate are deformed in compression, the deformation increasing from zero at the neutral axis to a maximum at the surface, while the outer part of the plate is deformed in tension.

During expansion, the inner layers of a pipe wall are deformed in tension and the outer layers receive further deformation in tension. In the flattening of a pipe section to provide testpieces, the inner layers are deformed in tension and the outer layers in compression. These deformations are summarized in Fig.1.

The properties of line pipes, like all structural steels, are controlled by the microstructure which in turn is determined by:

(i) the effects of the alloying elements on the kinetics of transformation and the formation of intermetallic compounds, i.e. the effects on the basic structure
(ii) the effect of secondary constituents on the structure, such as inclusions, which are in turn controlled by
(iii) steelmaking and casting processes and hence by the plant available for making and treating steel
(iv) the properties required by the pipeline engineer.

These groups of practical parameters determine the selection of steel compositions and steel treatments and, when taken together with our theoretical understanding of the relationship between metal structure and properties, can be considered the 'weft and warp' of steel development, as illustrated schematically in Fig.2. There is indeed a wide variety of steel patterns available and in use today for pipe made in mills having different characteristics and being supplied to many different markets.

In this paper, we are concerned primarily with the effects of alloying elements and processing of plates in relation to our theoretical understanding and the engineer's demands, but any decisions on steel composition selection must take all selection criteria into account.

There are many ways in which pipeline steels can be classified, but the most important division should be made on the basis of rolling, in as much as there are fundamental differences between the rolling of strip on continuous mills as used for spiral pipe, on the one hand, and plate rolled on reversing mills which is made into pipe by the U–O process followed by expansion, on the other.

Three types of steel with different basic structures having profoundly different effects on the mechanisms of deformation and the relationship between plate and pipe properties are used in both process routes. These are:

(i) the traditional ferrite–pearlite steels, albeit with low or reduced pearlite content, which exhibit a discontinuous stress–strain curve in the tensile test
(ii) ferrite–pearlite steels containing transformation products (bainite or martensite) to increase the work-hardening coefficient
(iii) steels containing polygonal ferrite and a major portion of a second phase, such as low-carbon bainite (sometimes called acicular ferrite) or islands of martensite and retained austenite which exhibit a continuous stress–strain curve in the tensile test.

The yield strength is determined by several parameters which can be expressed in a modification of the Hall–Petch[1,2] relationship for simple carbon steel (where only grain size is involved) such as that proposed by Morrison and Chapman[3]:

$$\sigma_y = \sigma_l + \sigma_{ss} + \sigma_{ppt} + \sigma_{disl} + \sigma_{text} + K_y d^{-1/2}$$

where

σ_y = yield strength
σ_l = lattice friction stress
σ_{ss} = solid-solution strengthening
σ_{ppt} = precipitation strengthening
σ_{disl} = dislocation strengthening
σ_{text} = texture strengthening
d = ferrite grain diameter
K_y = constant

As mentioned above, pipelines are structures operating

This paper was presented at the international conference 'Steels for line pipe and pipeline fittings', organized by The Metals Society and co-sponsored by the Welding Institute, and held in London on 21–23 October 1981. The conference was held as part of the celebrations of the 150th anniversary of the discovery of vanadium. The purpose of the conference was to bring together pipeline designers and constructors, and those from the steelmaking and welding industries, to examine trends in design, the potential of new steels, and new welding processes and testing methods. The proceedings of the conference, including discussions, are available as a proceedings volume.