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(討15) Observations on the Versatility of Mn-Mo-Nb Controlled-Transformation Steels

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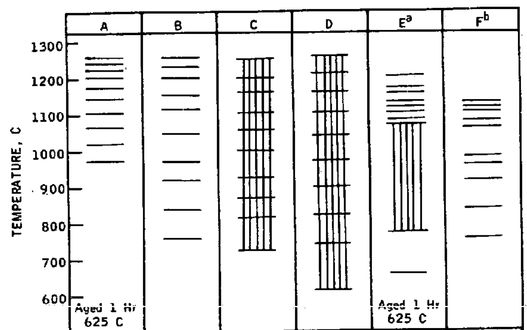
Further work has been done on the development of Mn-Mo-Nb steels since the first presentation at Kyoto in 1971. The major laboratory efforts since that time have been directed at a more thorough understanding of how variations in the hot-rolling process can be used to modify the final microstructure and associated mechanical properties. Some of the modified practices developed in the laboratory have been verified by commercial mills throughout the world. Work has also been done to evaluate the weldability of this type of steel, but those results will be reported elsewhere. This presentation is directed at describing the broad range of properties that can be developed from a relatively narrow range of compositions in 13-mm plates that are air cooled from the finishing temperature.

Some representative heating and hot-rolling schedules are schematically illustrated in Figure 1. Schedules A through D represent practices carried out both commercially and in the laboratory while schedules E and F are laboratory practices not yet verified in the mill. The corresponding minimum mechanical properties and suggested applications for the resulting steels are also shown. The uppermost horizontal line in the processing schedule representations in Figure 1 indicates the slab reheat temperature. Each successive horizontal line represents approximately one-tenth of the total rolling reduction, which in some cases represents more than one pass. Vertical lines passing through a region of temperature indicate that water cooling was used either during rolling or in between passes. The minimum mechanical properties listed are based on transverse data from commercial scale mill trials of rare-earth-treated steel.



Minimum Properties	A	B	C	D	E[a]	F[b]
YS, kg/mm^2	63	46	50	53	70	45
TS, kg/mm^2	70	63	67	70	80	60
$_v$TrS, C	30	-60	-75	-75	-25	-125
$_v$Tr 40 ft-lb, C	0	-75	-75	-30	-25	-125
$_v$E$_{20}$, kgm	6	8	7	6	10	12
APPLICATION	Structural	Line Pipe	Line Pipe	Line Pipe	Structural	Cryogenic

[a]Based on longitudinal data from 0.5% Mo steel.
[b]Based on longitudinal data from 0.02% C steel.

Figure 1 Processing Schedules and Minimum Properties for 13-mm Plates of 0.05% C - 1.6/2.0% Mn - 0.25/0.32% Mo - 0.06/0.10% Nb Steel

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In order to understand the relationships between processing and properties presented, several key points regarding the response of this steel should be kept in mind:

1. Only limited recrystallization of the austenite can take place below 1000 C because of the presence of niobium carbonitride precipitation.
2. Because of the relatively large amount of niobium present, a large strengthening potential exists if precipitation can be delayed until during or after transformation, but intermediate temperature hot rolling tends to reduce this potential by promoting a coarse precipitation in the austenite.
3. The molybdenum addition exerts a strong effect in inhibiting transformation to polygonal ferrite, but low-temperature rolling accelerates the formation of polygonal ferrite.

The examples in Figure 1 show how the above effects can be controlled to produce a broad spectrum of properties. Schedule A, which includes aging, produces a high-strength, completely acicular ferrite transformation product. This steel is suitable for many structural applications, but lacks the toughness required for arctic gas transmission pipe. Processing accroding to Schedule A allows a maximum rate of production because of the high finishing temperature. Aging can be performed off-line.

Schedule B is a conventional pipe skelp rolling practice. The lower finishing temperature produces a highly worked austenite from which to transform. Transformation from the highly worked austenite produces high toughness in a microstructure of fine-grained polygonal (ASTM 13 to 14) mixed with acicular ferrite. This product is well suited to being formed into U-O gas transmission pipe to meet an X-75 specification, as will be described below. Schedule C is similar to Schedule B except that enough water cooling was used during rolling to allow continuous rolling without delays. Such a process does not allow time for as much niobium carbonitride precipitation during rolling. Steel processed to this schedule undergoes greater precipitation strengthening during and after transformation. It has a toughness level approximately equal to steel processed to Schedule B, with a higher yield strength level. Schedule D is a modification of Schedule C that involves lowering the finishing temperature to impart some reduction during transformation. This cold working of the ferrite produces higher yield strength with some sacrifice in toughness. Commercial data indicate that properties suitable for arctic gas transmission pipe can be developed at a thickness of 16 mm, and laboratory data indicate that similar properties can be developed at a thickness of at least 19 mm, with processing similar to Schedule B.

Schedules E and F are based on data from longitudinal specimens from plates made in the laboratory. The effort was directed to maximizing strength in Schedule E and toughness in Schedule F. In Schedule E water cooling is used to cool the plate through the temperature range where coarse niobium carbonitride precipitation is most likely to occur, and no rolling is performed in this range. Such a schedule maximizes precipitation upon subsequent aging. In addition, the low finishing temperature produces some cold working of the austenite. Schedule F achieves high toughness suitable for cryogenic applications. It employs a low reheat temperature and a large amount of rolling reduction in the temperature range that maximizes coarse niobium carbonitride precipitation in the austenite. The microstructure is a very fine-grain polygonal ferrite of grain size ASTM 13 to 14. Such a structure is unusual for a 13-mm-thick air-cooled plate, but it is relatively easy to produce in the Mn-Mo-Nb steel.

An important aspect of the mechanical behavior of Mn-Mo-Nb steel is the stress-strain behavior. The as-rolled steel does not exhibit a yield point. This characteristic is of particular significance in the manufacture of pipe by the U-O process. Such pipe requires an expansion operation after forming and welding to properly shape the pipe. When this expansion of 1 to 1-1/2% strain is performed on conventional ferrite-pearlite steel, the strength increase is often barely enough to overcome the loss of strength due to a Bauschinger effect produced by forming. Representative stress-strain curves are shown in Figures 2 and 3 for both skelp and expanded pipe of steels processed to Schedules B and C, respectively. The absence of a yieldpoint elongation in the as-rolled steels results in a minimum strength increase of 7 kg/mm^2 for a 1-1/2% expansion. The end result is an X75 grade U-O product from Schedule B and an X-80 product from Schedule C. Accordingly, it is believed that an X-85 product can be developed from Schedule D. These strength increases are attained with no significant loss of toughness.

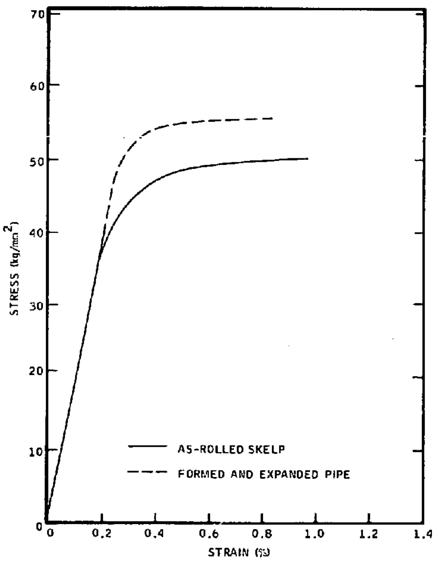

Figure 2 Stress-Strain Curves for Mn-Mo-Cb Steels Processed to Schedule B

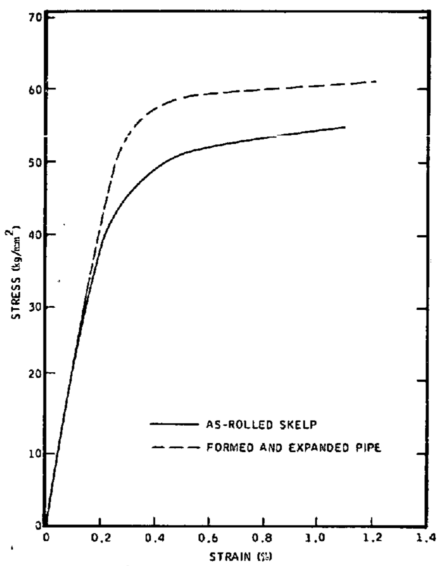

Figure 3 Stress-Strain Curves for Mn-Mo-Cb Steels Processed to Schedule C