Summary—Steels Session

The papers for the Steels Session of MiCon 78 were chosen to be consistent with the objectives of MiCon and to emphasize the theme of the symposium, namely, energy generation and related applications. The Steels Session had ten invited papers, of which six addressed the subject of high-strength low-alloy (HSLA) steels for Arctic linepipe application. The papers were complementary to one another in terms of the overall theme, and each one dealt with specific topics such as: alloy composition and processing, microstructural control, stress corrosion cracking and hydrogen embrittlement, accelerated cooling, and regression analysis and prediction of plate and pipe mechanical properties. The keynote paper discussed the need for improved wear- and abrasion-resistant steels for components in advanced fossil energy conversion systems such as coal gasification plants. In the area of turbine materials, which are susceptible to temper embrittlement at the operating temperatures involved, Viswanathan's paper reviewed the most common steels used for this application (Cr-Mo, Cr-Mo-V, Ni-Cr-Mo-V) and provided an insight into the role of microstructure in interpreting the embrittlement susceptibility as effected by transformation product and strength level. In the area of pressure vessel steels, the Swift and Smith paper considered A533-B steel and describes a procedure for predicting the microstructure of heavy-gage plates as a function of carbon equivalent and cooling rate. The final paper by Diesburg considered the problems of drilling large-diameter deep oil wells and, because of the high stresses involved, the need for rolling-cutter rock bits having high levels of hardenability.

The intent of this summary is not to abstract each of the papers presented, but rather to comment on how their salient highlights fit into the overall theme of the symposium. In Prof. Zackay's keynote paper, he described the utilization of composition control to provide the desired combination of mechanical properties required in advanced fossil energy conversion systems. In this context, high hot strength up to 593°C (1100°F) with adequate room temperature toughness is required for screw feeders. Secondary hardening alloys with combinations of up to 3Si and 3Al retard the tempering reactions, and optimum improvement in room temperature toughness is obtained by combining 1.5Al and 1.5Si. However, additions of more than 2Si cause intragranular fracture after tempering at 550°C.

Cohen and Hansen's paper, "Microstructural Control in Microalloyed Steels," was based on the premise that a fine ferritic grain size is essential to develop the best strength toughness combination in microalloyed steels. Structural refinement of the ferrite was shown to depend on control of the austenite structure during rolling, coupled with control of the austenite-to-ferrite transformation kinetics. The finest ferritic grain sizes evolve on transformation from unrecrystallized austenite, and the mechanism and control of the austenite recrystallization reaction were discussed. The subsequent transformation of unrecrystallized austenite was followed, and it was stressed that any structural refinement gained during rolling may be further maximized by appropriate control of the transformation kinetics via alloying or process controls.

The paper, "Evaluation of Steels for Arctic Line Pipe," by Abrams and Roe was a practical demonstration of microstructural control to improve the strength and toughness properties described by Cohen and Hansen. Extensive property data were presented from seven full-scale mill trials, which were used to predict the plate and pipe properties based on chemistry and processing. The improved strength and toughness properties are associated with a fine ferrite grain size and a high percent of fine-grain ferrite patches (fgfp). Specifically, for a vanadium-columbium (VCb) grade, to assure an 85 percent shear fracture appearance below −23°C (−10°F) in the pipe, the control-rolled plate must have a grain size number greater than ASTM 11 and a percent fgfp value greater than 75 percent. Lower slab reheating temperatures reduce the amount of duplex ferrite microstructure common to severely control-rolled steels and provide further improvement in toughness as characterized by the Battelle Drop Weight Tear Test.

In the paper, "The Control of Microstructure by Processing Parameters and Chemistry in Arctic Line Pipe Steels," by Ouchi et al, the authors evaluated a series of columbium (0.02 to 0.05 percent) and vanadium (0.03 to 0.09 percent) steels and studied the effects of controlled rolling and quench and temper heat treatment (after rolling) on microstructure and mechanical properties. In the control-rolled condition, these steels exhibit ferrite/pearlite or acicular ferrite microstructures and develop yield strengths of 70 to 75 ksi. Accelerated cooling after control-rolling increased the yield strength to 80 to 85 ksi due to a more refined structure consisting of ferrite and bainite. The quench and temper heat treatment by induction heating of pipe produces a ferrite-bainite-martensite microstructure, retaining a fine grain size and further increasing the yield strength to 100 ksi. This heat treatment eliminates variations in toughness across the heat-affected zone (HAZ) and results in improved resistance to hydrogen-induced cracking and H_2S stress corrosion cracking.

The role of hydrogen-induced cracking of microalloyed steels in the 40 to 100 ksi strength range was described in detail by Malcolm Gray, who presented the paper, "High-Strength Microalloyed Pipe Steels Resistant to Hydrogen-Induced Failures," by Parrini and DeVito of Italsider. The susceptibility to H_2S stress corrosion cracking was found to increase with increasing tensile strength. Above 120 ksi tensile strength, the failure was always intragranular, whereas below 80 ksi tensile strength, the failure was always ductile. This susceptibility was also related to steel cleanliness and the degree of inclusion elongation. Lower levels of MnS via desulfurization and higher finish-rolling temperatures reduced the degree of cracking, but the major improvement was associated with rare earth additions. Another approach to the hydrogen cracking problem in sour gas environments was to make the weld metal cathodic with respect to the HAZ, thereby preferentially attracting the hydrogen to the weld metal. This cathodic protection was accomplished by additions of 0.5Mo and 0.4Cr to the welding rod.

Processing, mechanical properties, and microstructure interrelationships for an acicular ferrite steel containing Mn-Mo-Cb were described in the Stelco paper, "Controlled Processing of Molybdenum Bearing Line Pipe Steels," by Delvecchio, Hood, and McCutcheon. The acicular ferrite grades are attractive for Arctic line pipe because in the plate form the yield strength is relatively low, about 60 ksi, which upon forming to pipe and hydraulic expansion achieves X70 to X80 levels due to the continuous yielding behavior and appreciable strain hardening. However, these grades typically are very low-carbon and high-manganese and offer the disadvantage of BOF melting problems and added alloy costs. Delvecchio and co-workers found that both the low- and high-manganese grades are suitable for X70 Arctic applications. However, at the more economical 0.2Mo level, the higher manganese grades consistently provided higher yield strengths and required less low-temperature rolling.

Coldren et al reported on their laboratory study of Mn-Mo-Cb steels finish-rolled moderately below Ar_3. In this study, they rolled 19 mm (3/4 in.) plate into the two-phase region to determine the relative effects of ferrite grain refinement, dislocation substructure and Cb (C, N) precipitation strengthening on the strength and toughness. They found that stress-assisted precipitation and dislocation substructure can effectively increase the strength without adversely affecting the toughness, and these mechanisms were most efficient in plates with 30 to 40 percent deformed ferrite that was given a 20 percent reduction on the last pass. Increasing the molybdenum content from 0.2 to 0.4 percent reduced the yield point elongation, and in plates with as little as 11 percent deformed ferrite, there was continuous yielding. This behavior, as mentioned previously, offers the capability of making an X75/X80 expanded line pipe from a molybdenum-containing alloy grade. However, the effect of this work hardening on notch toughness at these high-strength levels would have to be more fully studied before an X80 grade could be exploited.

One of the many factors that influence toughness is reversible temper embrittlement, which manifests itself as an increase in the ductile-to-brittle transition temperature of the steel. The problem has assumed even greater importance in recent years in view of the findings that the susceptibility of steels to cracking in hydrogen and stress corrosion attack is also increased due to prior temper embrittlement. The critical temperature range over which embrittlement occurs often coincides with the operational or heat treatment temperature for many of the steels used by the petrochemical and other energy-related industries. Results have recently been reported relating microstructural variations produced by varying the transformation product and/or the tensile strength level to embrittlement susceptibility and in turn to the susceptibility of cracking in adverse environments. In his paper, "Influence of Microstructure on the Temper Embrittlement of Some Low-Alloy Steels," Viswanathan provides a critical review and interpretation of the results for Cr-Mo-V, Ni-Cr-Mo-V, and 2.25Cr-1Mo steels.

The mechanical properties of heavy-gage plate for pressure vessels is determined by the microstructure and tempering parameters. The microstructure is in turn controlled by the hardenability and post-austenitizing cooling rate. Using the carbon equivalent to account for the hardenability effects of the steel chemistry, Swift and Smith studied the effects of composition and cooling rate on the microstructure of A533-B steel. Equations were developed from the experimental data to predict the microstructures, and comparison with the microstructures to commercial heats showed that the predictions were in good agreement.

In view of the energy shortage and its increasing cost, it is now economical to recover oil and gas from known deep reserves, which require large-diameter shafts. The replacement of worn or broken rock bits during the drilling of these deep shafts is obviously undesirable from the standpoint of cost and productivity. Accordingly, the rolling-cutter rock bit is an integral part of making the drilling operation efficient. In most instances, the best combination of properties for these rock bits is obtained by carburizing and quenching and tempering. In his paper, "High Hardenability Carburizing Steels for Rock Bits," Diesburg describes the excellent performance of EX55 (0.87Mn, 0.58Cr, 1.85Ni, 0.75Mo) in impact fatigue, high-cycle fatigue, impact fracture stress, and plane strain fracture toughness tests. Comparison of EX55 grades with high-nickel SAE 4800 grades indicates that the improved hardenability of the EX55 grades would be suitable for rolling-cutter rock bits for deep shaft drilling.

In conclusion, I would like to stress the excellent participation of the authors and others attending the symposium. The knowledge and enthusiasm of the authors were apparent in their papers, some of which represent years of experimental work. In addition to the value of the papers themselves, there are the fine points and interplay of ideas in the discussions, which have been grouped together and appended to the volume of Steels Session papers.

I would also like to take this opportunity to thank each of the authors, reviewers, and participants for making the Steel Session of MiCon 78 such a rewarding experience for all of us.

Halle Abrams
Homer Research Laboratories, Bethlehem Steel Corporation, Bethlehem, Pa., session chairman.