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Editorial

Recent Developments in Medium and High Manganese Steels

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1. Introduction and Scope

A huge amount of intellectual effort is currently being devoted to the study of medium and high manganese steels due to the diverse and impressive mechanical properties that can be achieved with these steels. There are a wide range of alloys are in development for applications as diverse as automotive thin sheets for vehicle light-weighting, to cryogenic plates for liquid natural gas (LNG) transport. In this Special Issue of *Metals*, nine high-quality contributions covering a wide range of important topics are presented. These nine papers address issues such as solidification/inclusion formation, hot ductility, low-density alloys, innovative thermomechanical processing, the comparison of medium manganese with quench and partition (Q&P) alloys, continuous galvanising, deformation and fracture, weldability and, finally, a comprehensive review on hydrogen embrittlement. Hopefully, this diverse collection will offer valuable insight into the state-of-the-art development of this class of steels, and illustrate the current problems/knowledge gaps that preoccupy the community of academic and industrial researchers who are working on these complex and fascinating alloys.

2. Contributions

Starting from the beginning of the steelmaking process, Lan et al. [1] studied the effect of Al and Nb additions on the inclusion populations of Fe-0.7C-(16–17)Mn TWIP steel air induction melts. They found that the number density of all inclusions (oxides, sulphides and nitrides) decreased as the Nb content increased, up to 0.08 wt.%. This was attributed to the formation of complex non-metallic inclusions containing NbC. Yang et al. [2] studied the hot ductility of an as-cast Fe-15Mn-0.58C-2.3Al TWIP/TRIP grade using slow strain rate testing in a Gleeble simulator. The authors did not detect any ductility troughs in the temperature range of 600–1310 °C, and noted that the minimum reduction of area at fracture was 47.3% at 1200 °C. The fracture surfaces showed no evidence of brittle failure, suggesting that the alloy in question had excellent hot ductility, and thus should be suitable for continuous casting. Piston et al. [3] reported the effect of thermomechanical processing on low-density, hot-rolled, annealed and aged Fe-18Mn-10Al-0.9C-5Ni plates. They showed that the presence of δ ferrite stringers and the precipitation of κ-carbide and B2 (Fe, Ni)Al phases can contribute to strengthening, but are all detrimental to ductility and to Charpy impact toughness. The latter is a serious challenge for alloys with high Al content.

Two papers focused on the influence of thermomechanical treatments on cold-rolled strips. Poling et al. [4] compared the effect of deformation temperature on the mechanical properties of two third-generation steels: Fe-0.3C-2.6Mn-1.6Si processed as a Q&P steel (martensite and retained austenite) and a medium manganese alloy, Fe-0.14C-7.1Mn-0.2Si (ferrite and retained austenite). They observed that the work-hardening rate, UTS, and elongation of the medium manganese alloy all changed dramatically in the temperature range of −10 °C to +115 °C, whereas the Q&P alloy properties were much more stable across a similar temperature range. This was attributed to a significant increase in austenite stability with increasing temperature, and the onset of dynamic strain aging (DSA) in the medium manganese steel. Huang and Huang [5] subjected a Fe-10Mn-0.4C-2Al-0.26V

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alloy to a novel processing route called D&P (deformed and partitioning). This involves hot rolling followed by warm rolling (FRT 350 °C), followed by (optional) intercritical annealing, cold rolling (0–35% reduction), and finally a short partitioning treatment in the temperature range of 350–500 °C. Some very impressive longitudinal tensile properties were demonstrated. The authors determined that the intercritical annealing step could be eliminated, and the alloy's properties could be optimised by choosing the correct combination of partitioning temperature and cold rolling reduction.

Bhadhon et al. [6] studied the response of a cold-rolled medium manganese TRIP steel Fe-0.2C-6Mn-1.7Si-0.4Al-0.5Cr to different continuous galvanising (CGL) compatible temperature cycles. The effect of changing the as-cold-rolled microstructure from tempered martensite and carbides to fresh martensite, using an austenitising and quenching (AQ) step, carried out before CGL annealing, was also investigated. It was found that CGL compatible processing was not successful when starting from the standard as-cold-rolled structure. However, with the additional AQ step, the authors showed that 3G properties could be obtained under realistic CGL-compatible conditions. Kang et al. [7] reported on a fundamental study of the effect of specimen geometry and strain rate on dynamic strain aging (DSA) and fracture of Fe-17Mn-0.9C-0.5Si-0.3V austenitic TWIP steel. They showed that the mean flow stress, the mean strain hardening rate, and the mean strain rate sensitivity parameters were all independent of the specimen's geometry (flat vs. round), and were uncorrelated with the presence or type of PLC bands, or the critical onset strain for band formation. However, both the fracture strains and stresses and the PLC behavior were highly geometry and strain rate-dependent. DSA and PLC instabilities appeared to play an important, but as yet unclear, role in promoting premature necking and final fracture.

Due to their excellent low-temperature properties, fully austenitic TWIP grades are strong candidates for LNG tank construction. Ren et al. [8] investigated the mechanical properties of multipass welded joints in the cryogenic austenitic TWIP plates of Fe-24Mn-0.6C-0.5Si-1.9Al-0.3V composition. High heat input welding is known to result in poor HAZ toughness in these alloys. Significant reductions in the tensile elongation of the weld joint, compared to the base metal, were observed at room temperature and at −196 °C. A Charpy V notch test at −196 °C showed a strong decrease (from ~120 J to ~55 J) in the impact energy in the weld metal and in the CGHAZ region. The authors attribute this to inhibited twinning behavior due to severe C-Mn-Si segregation and depletion in the CGHAZ. Nevertheless, the properties met the requirements for LNG tank construction. Finally, Cho et al. [9] compiled an extensive review of the recent publications on hydrogen embrittlement in medium manganese steels. This is an important and timely contribution to a crucial subject that may well determine the success or failure of cold-stamped medium manganese sheets in automotive applications. The authors provide some welcome clarity to a difficult and sometimes contentious subject, describing the relative importance of parameters such as retained austenite stability, volume fraction, and morphology. Some useful suggestions for alloying and microstructural engineering strategies to improve resistance to H embrittlement are also given.

3. Conclusions

These nine contributions illustrate the breadth and diversity of the current research on medium and high manganese steels. The scientific challenges remaining are considerable, especially for medium manganese alloys where the complexity and finesse of the microstructures and the multiple competing deformation mechanisms are quite astonishing. A clearer understanding of the structure–property relationships of these metals is further complicated by their strong temperature and strain rate dependence. Consequently, much research is still required on this topic. The long-term success or failure of these steels, as measured by the development of commercial products, is as yet unclear. High manganese alloys on the other hand are already long established (Hadfield steels) and innovative TWIP steels are pushing into exciting new areas (cryogenic plates). However, early efforts to apply TWIP concepts for automotive sheets have not been met with great success. Whether medium manganese steels will have a better chance of superseding the existing first-generation AHSS or competing third-generation metallurgies (CFB, Q&P) in automotive applications is still an open question.

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