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Austenitic Manganese Steel: A Possibility of Life

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ABSTRACT

Hadfield manganese steels are traditionally used in technologies. Instability in microhardness appears from subsurface multi-twin formation than dislocations or grain boundaries. Increasing load needs new materials than Hadfield manganese steel, which can form uniformity in properties after joining. Austenitic manganese steel has high manganese content (10%–14% wt Mn). Characteristics of austenitic manganese steel are good in toughness, ductility, and wear resistance. Martempering has prescribed to be the best heat treatment after cast formation to remove embrittling carbides from microstructure.

Keywords: *austenite, crusher jaws, Hadfield manganese steel, hardness, manganese, railway point, toughness*

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INTRODUCTION

Sir Robert Hadfield invented original austenitic manganese steel, containing about 1.2% C and 12% Mn in 1882. Hadfield's steel has been unique because of combined high toughness and ductility with high work-hardening capacity, usually good resistance to wear and possession of slow crack propagation rates. These non-magnetic steels harden in use, or prior to service can be surface-hardened by mechanical or explosive means to as high as 450 BHN. Hadfield's austenitic manganese steel performs the best when its grain boundaries are free of carbides. Works have been done to modify original Hadfield steel by addition of other alloying elements, by varying its composition or subjecting it to various treatments in order to meet different engineering applications. Non-uniform distribution of micro-/nano-indentation hardness has measured with hardness variation of about 30% in different grains as well as in different regions or even in same grain of deformed Hadfield high manganese steel. These were caused not mainly by austenite grain boundary and grain orientation of indentation plane, but by underlying non-homogeneous twinned substructures. Line speed of trains has raised pressures on railway rolling stock, axis, and intensity of transportation by new types of cars and locomotives. Railway crossover has been one of the most complex elements of railway, not only because of its construction, but also because of its intensive wearing. Frogs, wing rail, and actual frog point have been parts of railway crossover

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prone worn most quickly. As a wear-resistant material, austenitic manganese steel is commonly used in crushing machine components, railways, and heavy equipment components.

HADFIELD MANGANESE STEEL – VARIATION IN MICRO-HARDNESS

Qian et al. [1] have discussed distribution of micro-/nano-indentation hardness and microstructures of deformed Hadfield high manganese steel experienced by means of micro-/nano-indentation tests and optical and electron microscopic observations. Indentation tests have demonstrated existences of non-uniform distribution of hardness about 30% in different grains and in different regions of the same grain. Microscopic observations have indicated underlying non-homogeneous substructures, i.e. twins, dislocations, to be closely associated with non-uniform work hardening in deformed Hadfield steel. Effects of austenite grain boundary and grain orientation of indentation plane have not been significant. Hadfield high manganese steel, with full austenite microstructure at room temperature, has been used in variety of applications such as railway crossings, crawler treads for tractors, and impact hammers. Properties of relevance have been excellent work-hardening rate, high toughness, and high wear resistance. Correlation between excellent work-hardening properties of Hadfield steel with its evolved microstructures has been described from the following observations. Deformation and work-hardening properties of Hadfield steel have been assessed by uniaxial tension or compression tests and also by hardness measurements. Microscopic observations have revealed that evolved substructures of Hadfield steel have been subjected to non-uniform deformation and consequent work hardening. This relation has suggested for failure analysis of practical industrial products, since locally concentrated straining associated with non-uniform work hardening has tended to initiate damage and cracking. Other evaluation methods have been degree of straining heterogeneity due to mechanical twinning of Hadfield steel as observed by digital image correlation method. Other factors that influenced such anomaly have been grain boundary, grain orientation of indentation plane, as well as microstructures under indentation tip expected in deformed Hadfield steel. Table 1 represents mechanical properties of Hadfield steels.

Table 1. *Mechanical properties of investigated Hadfield steel.*

Elongation to fracture, δ/%	Reduction in area, δ/%	Ultimate tensile strength, σ_b/MPa	Impact toughness, σ_k/J cm^{-2}	Hardness, HV
35.8	22.9	840	320	225

Higher hardness in sub-surfaces has been multiple-twin regions and lower hardness in dislocation-prevailing regions. Investigations have explored crack initiation to relate incompatibility of deformation due to non-uniform hardness distribution in deformed Hadfield steel.

HADFIELD MANGANESE STEEL – REPLACEMENT BY BAINITIC CAST STEEL

Parzych and Tasak [2] have discussed about the influence of heat treatment on microstructure and properties of sample cast assigned as material to use for frogs in railway crossovers. Materials used in railway industry for frogs, i.e. manganese cast steel and forged pearlitic steels have not fulfilled conditions of exploitation for railway. One of the solutions has been cast steel with bainitic or bainite–martensite microstructure. These have allowed to gain high resistance properties, i.e. R_m = 1400 MPa, $R_{p0,2}$ = 900 MPa, and hardness = 400 HBW. Cooling rates of rail type UIC60 has

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showed possibility to reach bainitic microstructure in cast of frog. Microstructures of lower bainite have advantageous influence on cracking resistance. Parameters of heat treatment, i.e. critical temperatures, have been determined by dilatometric methods. Heat treatment consisted of normalizing those prepared it to farther process by resistance welding. This has been necessary to join by non-butt joint method and has been able to operate lines of trans-continental systems of conventional rail, with maximum speed of 200 km/h with pressure on axis not lower than 230 kN. Butt joints, i.e. fish-plate joints, have not fulfilled these requirements. Only non-butt joints have fulfilled these demands, e.g. resistance butt welding and thermit welding. Traditional usages for rail frogs have been forged steel with pearlitic microstructure (R260) or Hadfield steel (L120G13). Joining of different materials of different mechanical and electric properties and different thermal conduction has lead to problems to lack microstructure stability. Prevention of problems has joints made with buffer layer from austenite steel, Fe–Ni alloys or pure nickel. The authors have discussed influence of heat treatment, i.e. normalizing on microstructure and properties of bainitic cast steel used on frogs in railway crossovers. This heat treatment has prepared material likely to process by resistance welding. Cast steel has been material for frogs in railway crossovers to fulfill microstructure and hardness requirements. Critical temperatures (Ac_{1s}, Ac_{1f}, Ac_3) have been estimated by dilatometric methods, which allowed to set parameters of heat treatment correctly. Confirmed heat treatment of raw cast has caused complete crystallization of original grain of austenite or homogeneous microstructure as necessary for further process of resistance welding. CCT diagram has showed strong bainitic character of examined cast steel and enabled correlation between microstructure and mechanical properties after heat treatment.

HADFIELD MANGANESE STEEL – CONVENTIONAL PROPERTIES

Ibitoye et al. [3] have discussed the influence of some heat treatment procedures on structure and mechanical properties of cast ASTM A grade B-4 steel. Formation of grain boundary carbides has been a major problem. Some cast ASTM A grade B-4 steel samples have quench-hardened, martempered and tempered. As-cast and heat-treated samples have thereafter tested for tensile strength, yield strength, impact strength, ductility and hardness. Some of the samples have also been prepared for metallographic examination and their microstructures have been studied. Microstructures have been mainly austenite matrix with or without carbides at grain boundaries and in austenitic grains. Measured mechanical properties are varied and depended on the presence or absence of carbides either at grain boundaries or at both grain boundaries and in grains of austenite matrix. The authors have suggested two of the heat treatment procedures to be appropriate as post-casting processes suitable for ASTM A 128 grade B-4 steel components designed to function under condition in which impact strength and hardness have simultaneously required. As-cast condition has been difficult to obtain austenitic structure free of grain boundary carbides. The presence of grain boundary carbides has been detrimental to strength and ductility, and has caused embrittlement of material to affect resistance to impact and abrasive wear. Wear resistance has become high but susceptible to earlier brittle fracture. Tempering of hardened austenitic manganese steels has promoted precipitation of carbides at grain boundaries and in grains. Volume fractions of these carbides increased with tempering temperature. In quench hardened and martempered conditions, austenitic manganese steel has been free of carbides both at grain boundaries and in grains. In martempering condition, austenitic manganese steels have better plastic flows attributed to decrease in overall thermal gradients and reduction in residual stresses associated with heat treatment operation. This has given better combination of hardness and toughness than when it has been in water-quenched condition.

AUSTENITIC MANGANESE STEEL – SOLID SOLUTION TREATMENT

Nurjaman et al. [4] have discussed the effect of solid solution treatment on hardness and microstructure of austenitic manganese steel. Solid solution treatment process of austenitic manganese steel, 0.6%wt C–10.8%wt Mn–1.44%wt Cr, was conducted by heating material at varied temperatures like 950°, 1000°, and 1050°C for 1 h and then quenching it in two different quenching media, i.e. oil and water. Further, samples were tempered at three different temperatures like 300°, 400°, and 500°C for 2 h. Treated materials were analyzed by Rockwell hardness tester to obtain information of material hardness and by optical microscope and XRD to investigate microstructure phases of treated materials. Heating austenitic manganese steel at 950°C for an hour followed by water quenching has dissolved all carbides in as-cast condition, and has resulted fully austenitic on its microstructure. Carbide precipitations occurred due to prolongation of soaking time in solid solution treatment and tempering process. Optimum hardness of sample has been 53.3 HRC, after heating material at 1000°C for an hour, followed by water quenching and tempering at 400°C for 2 h. Fully austenitic crystal lattice of face-centered cubic structure consisted of interstitials of carbon atoms and substitution of manganese atoms. It has the same structure as stainless steel, but has very low corrosion resistance. As-cast brittleness was caused by formation of carbide (Mn_3C) along with grain boundaries on its microstructure due to slow cooling in solidification process. Mechanical properties have been improved by addition of alloying elements, such as Nb and Ti for obtaining fine austenitic structure and hard-dispersed carbide. Solid solution treatment was commonly applied in austenitic manganese steel to obtain homogeneous austenitic phase on its microstructure. This heat treatment process included heating material at 1000°–1100°C and quench rapidly. This fully austenitic structure has transformed to martensite after work-hardening. It was called strain-induced martensite. Other heat treatment process has improved hardness of austenitic manganese steel, i.e. precipitation hardening. Reported artificial aging at 700°C for 2 h has increased hardness of austenitic manganese steel, which was caused by fine dispersion of carbide particles in austenite matrix.

AUSTENITIC MANGANESE STEEL - FAILURE OF CRUSHER JAWS

Olawale et al. [5] caused have discussed work-hardening behavior and microstructure of austenitic manganese steel in relation to premature failure of crusher jaws. Samples of sound and failed crusher jaws have studied about changes with depth from working surface to core by hardness and microstructures. Hardness gradient in failed crusher jaws was evaluated in addition to the presence of large carbides at both austenite grain boundaries and in austenite matrix. Failure of crusher jaws has been brittle fracture as a result of precipitates of carbides which were unable to absorb shock during impact working. The authors have prescribed failure occurrences as a result of inadequate quenching operations during manufacturing

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process that formed carbide precipitates to embrittle austenitic manganese steel. Consequences have been reduction in its ability to withstand shock and to create non-uniform plastic flow as per work-hardening introduced. Hadfield steels have the ability to harden in-depth in-service as well as by induced means. Work hardening is usually induced by impact, as from hammer blows. High-velocity light blows caused shallow deformation with superficial hardening, while heavy impact produced deeper hardening. Manganese steels have unequal ability to harden, e.g. manganese steel containing 1.0%–1.4% C and 10%–14% Mn have work hardened from initial of 220 HV to maximum of more than 900 HV. Hadfield steel is said to be a remarkable engineering alloy which in fully solutionized form has been soft and ductile, but when deformed, it has work hardened rapidly. Work-hardening mechanisms, impact wear, abrasive wear and alloying of austenitic manganese steel have hardened under repeated impact and abrasive wear, but have displayed remarkable toughness. Consequent evidences of surface treatment have also proved increases in surface hardness and wear resistance. Rate of work hardening depended primarily on the amount of carbon in solution in austenite matrix and the presence of fine dispersion of carbides. Presence, amount and dispersion of carbides have influenced the wear resistance of alloy. If carbides have formed interconnected grain boundary films, they have seriously impaired impact strength. Embrittling intergranular carbides were formed during solidification because of slow rate of cooling or precipitation during reheating at temperature range of 400°–800°C. Hadfield steel has been considered an alloy with inherent toughness, work-hardening characteristics, and excellent resistance to some types of adhesive and abrasive wears. These unique properties of Hadfield steel have made it a suitable candidate material for production of crusher jaws. Failure evidences have reported crusher jaws were used in crushing granite fractured across teeth, while some worn-out to paper thin. Failure of crusher jaws could have attributed to brittle fracture as a result of precipitates of carbides at grain boundaries and in grains. Inabilities of precipitated carbides to absorb shock under working conditions due to their embrittlement have reduced impact strength of failed crusher jaws. The authors have found decrease in hardness inwardly from working surface to core which has indicated that crusher jaws were work hardened in service. However, there has been no uniform plastic flow during work hardening of failed crusher jaws as compared with that of sound ones.

CONCLUSION

Austenitic manganese steel has 379 MPa of yield strength, 965 MPa of ultimate tensile strength, 190 HBN of hardness, and 169 J of Charpy V-Notch impact. Higher hardness in sub-surfaces has been multiple-twin regions and lower hardness in dislocation-prevailing regions. Investigations have explored crack initiation to relate incompatibility of deformation due to non-uniform hardness distribution in deformed Hadfield steel. Influence of heat treatment, i.e. normalizing on microstructure and properties of bainitic cast steel, was used on frogs in railway crossovers. This heat treatment has prepared material likely to process by resistance welding. Austenitic manganese steel alloy possesses unique resistance to impact and abrasion wear. It exhibits high levels of ductility and toughness and slow crack propagation rates, in comparison to other potentially competitive materials. It is also non-magnetic and can work harden during service or can be surface-hardened to as high as 450 HB by mechanical or explosive means prior to service. Failure of crusher jaw occurred as a result of inadequate quenching operation during manufacturing process that has resulted in the formation of carbide precipitates to embrittle jaw crushers. Subsequently, these have reduced the ability to withstand shock and created non-uniform plastic flow during work hardening.

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