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THERMOMECHANICALLY TREATED ADVANCED STEELS FOR STRUCTURAL APPLICATIONS

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ABSTRACT

It is true that earthquake and other accidents, especially accidents of passenger vehicles and associated damages are very unpredictable. However, degree of damages to human lives and properties due to various accidents can be minimized by using proper materials as well as design for buildings and auto bodies. Large volumes of steels are being used every day for civil constructions and various auto bodies. For the safety of residents of buildings and passengers of vehicles good quality steel undoubtedly can play a very important role. Considering the safety of various structures and people associated with them, thermomechanically treated advanced steels ushered a new horizon in the field of construction of buildings, bridges, auto bodies, etc. In this paper, various advanced steels developed for structural applications will be discussed with their merits and demerits.

***Keywords**: Thermomechanical treatment, Advanced structural steels, DP steel, TRIP steel, UFG steel.*

1. INTRODUCTION

Throughout the whole world, environmental pollution is really a very big issue. It is important to mention that heavy industrialization is significantly responsible for the overall worldwide environmental pollution. Till now, as engineering material, steel is used in the largest volume. As a result, steel industries are under tremendous pressure from the environmentalists to reduce the steel production. Considering the environmental pollution, auto makers are also trying to reduce the vehicle weight for lower fuel burning related air pollution. At the same time, structural design engineers are looking for high strength and earthquake resistant steel bars for reinforcing concrete to reduce the overall weight of the structures. However, it is really not so straight forward job, because any possible reduction in steel consumption (i.e. overall reduction in structural weight) must be adopted without compromising the safety of the users of buildings and auto bodies. In this situation, application of high strength steel rods/bars/sheets might provide necessary solution. Through the addition of various alloying elements, the strength of steel can be increased. But the key problem concerning this steel strengthening route is that it reduces the ductility of the steel as well as the bendability and/or stretch formability (1-4). In order to avoid problem related to inferior ductility, materials scientists have developed various advanced structural steels by proper microstructures of the steel through precise control of various thermomechanical treatment parameters. Thermomechanically treated steels might be plain carbon as well as alloy steels. The latter group of steels (alloy steels) are designed to achieve further higher strength along with other property requirements depending on service conditions [5-6].

The aim of this paper is to present various types of advanced structural steels developed so far and their benefits if they are used as structural steels as substitutes of conventional plain carbon or alloy steels.

2. RESULTS AND DISCUSSION

It is to be noted that there are various technological options to increase the strength of structural plain carbon steels such as by increasing carbon content, addition other alloying elements, decreasing ferrite/pearlite grain size, changing ferrite/pearlite structure to high strength bainitic structure by water spray/sudden cooling, proper cleaning of molten steels, thermo-mechanical treatment and so on [7]. Here in this paper, initiative will be taken to discuss techniques to increase the strength of steels by various thermomechanical treatments with their possible advantages. There are various thermomechanical treatment techniques such as quenching and tempering (QT, note: in Bangladesh some steel companies are marketing this type of product as TMT steel), severe refining the grain size of steels (ultrafine grained; UFG steel), controlling the soft and hard phases of the steels (e.g. dual phase; DP steel), retaining and controlling the proportion of unstable/metastable phases, i.e. phases with stress induced transformation behaviour (transformation induced plasticity; TRIP steel), etc.

2.1 QT or TMT Steel

This group of structural steel might be plain carbon or alloy type. In general, it is bar type product used for reinforcement of concrete. However, it can also be used for load bearing machine components or other structural applications. In the case of conventional bars, the hot rolled products are cooled naturally in the air. So, from surface to core, the microstructures remain fully ferrite-pearlite. But for QT/TMT steel bars, they are forced to cool suddenly by passing them through water chamber just after final rolling. So, the outer layer of the bar gets quenched with subsequent formation of tempered martensite at the outer layer. The structures of the core remain as normal ferrite-pearlite (Fig. 1) and there also exits a transition zone in between the outer tempered martensite and ferrite-pearlite core. Tempered martensite is a very strong phase, which provides high strength and relatively soft ferrite-pearlite structure at core provides necessary ductility of the steel. The stress-strain diagrams of individual phases of QT steel as well as the combined one are presented in Fig. 2.

Figure 1. Microstructure of TMT steel.

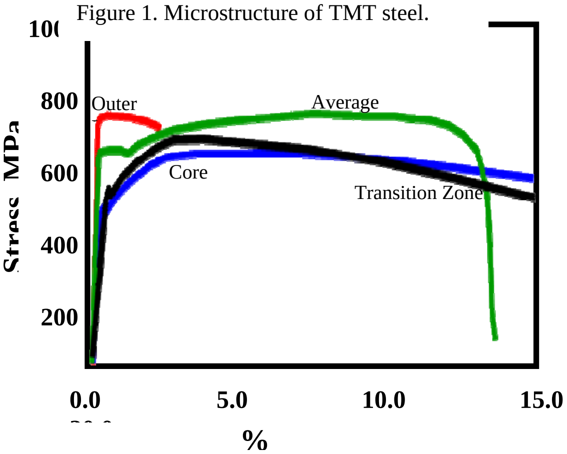

Figure 2. Stress-strain diagram of various phases in QT or TMT steel.

2.2 Ultra Fine Grain Steel

Grain refinement has been always one of the most important subjects in microstructure control of structural metallic materials and also an important field of research for physical metallurgists. The minimum grain size that might be achieved through conventional method is around 10 micron. Through controlled thermomechanically processed rolling, this value can be up to 5 micron [8]. However, it has become recently possible to fabricate the steel with ultrafine grained structures of which mean grain size is smaller than 1 micron. This is possible in carbon steel through heavy one-pass deformation at low temperature around 500^{o}C followed by rapid cooling of sheets or wire to achieve fine grain through controlled recrystallization [8]. It has been well accepted that decrease in ferrite-pearlite grain size causes increase in yield strength of the steel product as shown in Fig. 3 and a typical ultrafine grained ferrite-pearlite structure is shown in Fig. 4.

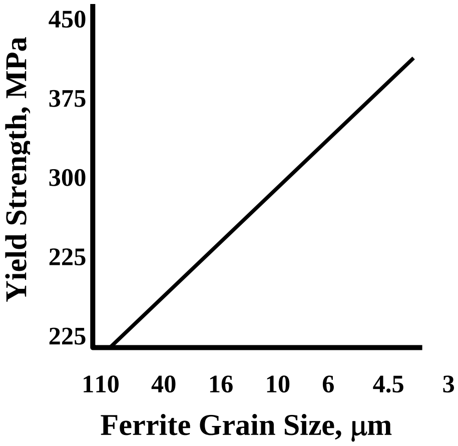

Figure 3. Effect of ferrite grain size on tensile yield strength of plain carbon steel.

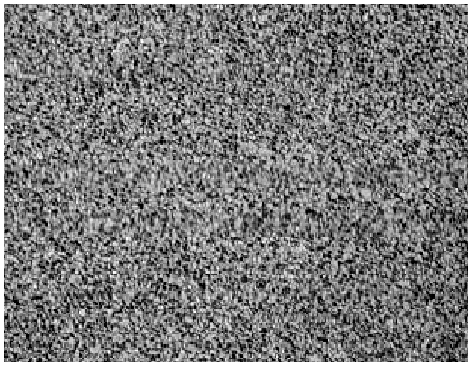

Figure 4. A typical ultrafine grained ferrite-pearlite steel.

The main limitation of this strengthening method is the gradual brittleness in the steel and that drastic decrease in thickness during rolling needs a very powerful rolling mill.

2.3 Dual Phase (DP) Steel

This is, in general, carbon steel with controlled amount of manganese and silicon content. During the production of this steel, the stock material is hot rolled with a precise rate at every specific temperature so that initially some ferrite grains may come out from austenite. Gradually the proportion of austenite becomes lower with relatively higher carbon content. This high carbon austenite then transforms to martensite/bainite due fast cooling after final deformation. Ferrite is a relatively soft phase, which ensures higher ductility. However, martensite/bainite is very strong which retards the deformation of soft ferrite under loading condition. So, at a certain stage, the resultant deformation becomes slower and thus the steel provides reasonably high strength. The microstructure of this steel is shown in Fig. 5.

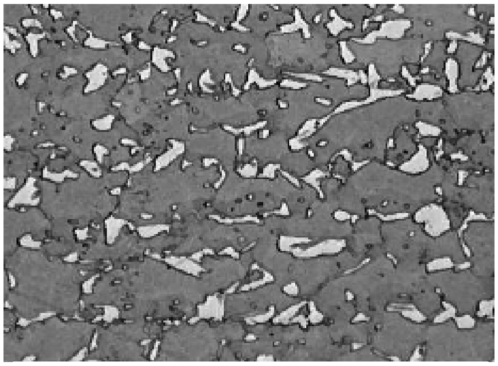

Figure 5. A typical ultrafine grained ferrite-pearlite steel

From this steel, high strength along with moderate elongation is achieved without adding any expensive alloying element. Because of high strength and ductility combination, the earthquake resistance of this steel also very good. However, so far the production cost of this steel is very high because of expensive heat treatment schedule along with precise control system. As a result, these steels are used in some advanced structural applications, e.g. in auto bodies.

2.4 Transformation Induced Plasticity or TRIP Steel

In this steel, similar to DP steel, ferrite matrix is strengthened by hard and strong martensite/bainite structures. However, retained austenite which is kept untransformed during the controlled processing helps to increase the ductility of this steel (9-11). So, TRIP steel is also termed as high strength multiphase steel. Because of retained austenite transformation during loading, TRIP steel shows higher ductility than that of DP steel. Because of higher strength, at the same time higher ductility, TRIP steel provides excellent earthquake resistance and resistance to crush as it has the capability to absorb energy under severe loading condition [12-14]. The microstructure of a typical TRIP steel is shown in Fig. 6 and the stress-strain diagrams of DP and TRIP steels are presented in Fig. 7. The unique advantage of this steel is that, during the severe shock of earthquake retained austenite absorbs energy to transform to bainite, which ultimately reduces the severity of earthquake related damages.

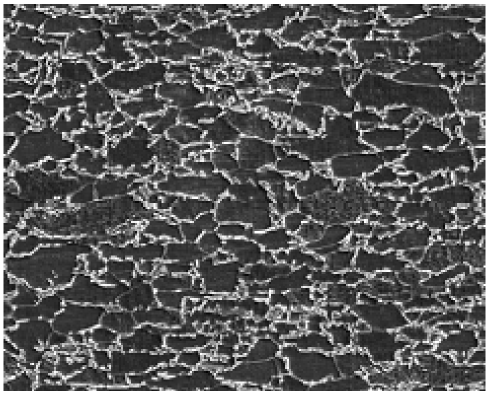

Figure 6. Microstructure of transformation induced plasticity (TRIP) steel.

The earthquake resistance of any structural steel depends on its energy release rate under cyclic loading. The energy release rate curves of conventional and TRIP steels are shown in Fig. 8. From this figure it is clear that TRIP steel has significantly higher energy release rate compared to that of its rival conventional steel, because TRIP steel shows a very high strength along with a very high percentage of elongation.

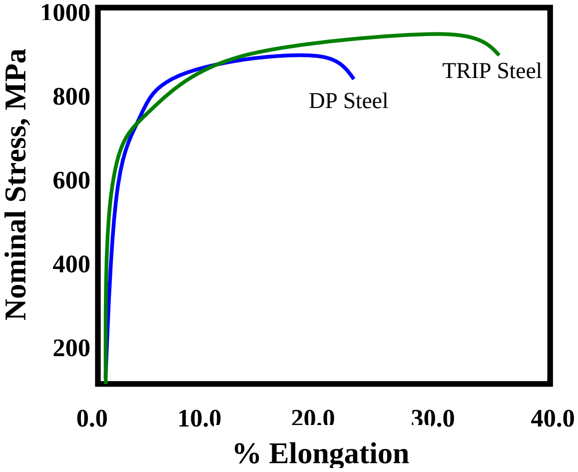

Figure 7. Nominal stress-strain diagrams of dual phase and transformation induced plasticity steels.

In order to produce TRIP steel, both chemical compositions, degree of deformation at different levels and corresponding temperatures and final cooling rate must be controlled properly. So, similar to DP steel, the production cost of this steel is also very high. Because of production cost, these steels are not commercially produced in many countries and that their applications are also limited in manufacturing various auto bodies.

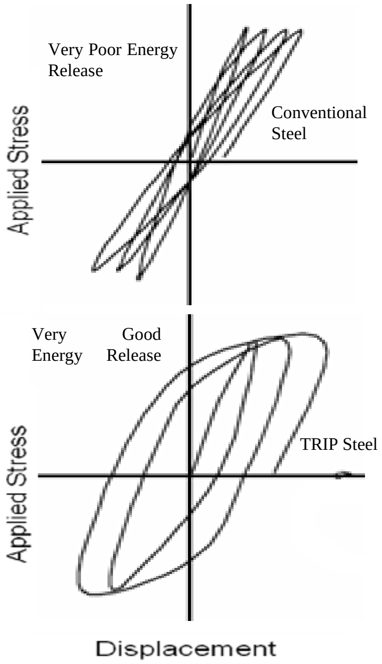

Figure 8. Energy Release behaviour of conventional and TRIP structural Steels.

3. CONCLUSIONS

Tensile strengths of structural steels can be increased by various ways. However, till now, thermomechanical treatment method is found to be the most efficient method of strengthening of steels without compromising the good combination of mechanical properties. The main benefits of the thermomechanically treated steel bars are due to relatively lower volume of steel consumption compared to any conventional steel in any structural application and their outstanding earthquake resistance. Another benefit of this method is that no expensive alloying element is required to increase the strength of the steel. If it is possible to reduce the production cost of thermomechanically treated steel and make this steel more popular, then there is no doubt that construction cost of buildings will be reduced to some extent. At the same time, safety of the building will also increase significantly, which is very crucial for a society with a heavy population like that in Bangladesh.

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