Advances in Steel Materials and Steel Structures in Japan

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Summary

Over the course of 150 years since the construction of Japan’s first cast iron bridge in 1868, Japan has become one of the most advanced countries in terms of steel structures. This advance is attributed largely to the contributions made by high performance steels. In Japan, steel-related innovations have enabled progress in steel structures to leap forward, and in turn, challenging new structures has given birth to further advances in steel materials. In this paper, the developments in steel structures and materials are reviewed and discussed.

Keywords: steel structures; bridges; buildings; towers; high strength steels; high strength wires; high performance steels; high tension bolts; seismic resistance; steel-making technologies.

1. Introduction

Infrastructure’s gross capital stock in Japan has reached a valuation of about 800 trillion yen (7 trillion US dollars), and a large amount of steel is used every year. There are also many notable steel structures in Japan. They include the "Akashi Kaikyo Bridge" (1998), which is the world's longest suspension bridge with a centre span of approximately 2km; "Tokyo Skytree" (2012), which is the world's highest self-standing tower (634m); and the high-rise building "Abeno Harukas" (2014), which with a height of 300m is probably one of the highest buildings built in an earthquake-prone region. These landmark steel structures were in fact realized by strong contributions from steel materials. This paper makes a historical review of steel structures and materials, and then, in the light of the further potential of steel, the future advances in steel structures are discussed.

2. Historical overview of steel bridges and their materials

Over a period of 30 years from the late 1960s until the early 2000s, around 500,000 tons (metric) of steel was used in the construction of bridges every year, and a maximum of about 90 million tons was recorded for the decade beginning in 1990. With such active bridge construction, the spans of suspension, cable-stayed and truss bridges have continued to expand, and at present the largest bridges have a maximum span of about 2000m (centre span), 900m and 500m, respectively. These spans were either the first or the second longest in the world when they were completed, and even today, the suspension bridge is the longest, the cable-stayed bridge is the fifth longest, and the truss bridge is the third longest in the world.

During the construction of the suspension bridge, the strength of the steel wire used in the cable increased approximately 200N/mm^2 in a single leap, leading to a new 1,800N/mm^2 class of high strength steel wire. This new wire made possible the realization of the world’s longest suspension bridge, the “Akashi Kaikyo Bridge”. When the conventional strength wires were applied to the bridge, engineers found that a total of four cables were required, two on each side. This would have led to significant increases in both the dead load and construction cost of the bridge. This problem was solved through a material innovation resulting in a dramatic improvement in wire strength.

3. Historical overview of steel buildings, towers and their materials

A considerable number of steel-frame buildings have been built in Japan, and about six million tons of steel has been used every year for the past 40 years or so. Almost 10 times more steel has been used in buildings than in steel bridges, and the steel consumption peaked in 1990 at about 12 million tons, which is comparable to the present day crude steel production of the UK.

The Kasumigaseki Building built in 1968, with a height of 156m, ushered in the dawn of high-rise buildings in Japan. Since then, other symbolic high-rise buildings have been built, such as the Tokyo Metropolitan Government No.1 Building (1991), the Yokohama Landmark Tower (1993) and most recently the Abeno Harukas (2014). In the category of self-standing towers, the Tokyo Skytree was built in 2012 and gained the title of world's tallest tower. Regarding the steel used in buildings, steel with a tensile strength of 600N/mm^2 class (YS=430 or 440) was first used in the Yokohama Landmark Tower in 1993, and then, in 1998 steel with a tensile strength of 800N/mm^2 (YS=620) was applied to the Kokura Station Building. These high strength steels differ from the steel used in bridges, and they have special properties for achieving larger inelastic deformation capacity.

4. Innovative steel materials and their contributions to steel structures

Coupled with the vigorous construction of steel structures, various innovative steels have been developed over the past decades. The steels developed in Japan tend to have the following three major characteristics. They include: "strength versatility" from high strength to low strength; "function versatility" such as weldability, fracture toughness and deformation capacity; and "section versatility" with a variety of sectional sizes. The following noteworthy and unique steel materials developed in Japan are outlined in this paper:

1) High strength steel plates: steels plates with tensile strengths of 600 to 1,000N/mm^2
2) High strength cable wires: steel wire with a tensile strength of 1,800N/mm^2
3) Super high tension bolts: super high tension bolts with a tensile strength of 1,400 N/mm^2
4) High performance steel for bridges: SBHS with yield strengths of 400 to 700 N/mm^2
5) Seismic resistant steel for buildings: high performance steels suitable for seismic design

5. Advanced production technologies for high performance steels

Advanced technologies contributing to the production of various high performance steels in Japan include; 1) steel cleanliness technology, 2) metallurgy for microstructure control, and 3) thermomechanical control process (TMCP) technology. The most notable is the TMCP technology, which can achieve both high strength and high fracture toughness under, in principle, the as-rolled condition. The TMCP technology is regarded as a breakthrough technology that opened the door to the wider application of high strength steels in steel structures.

6. Potential of steel materials, recent progress and various challenges

The typical strengths of steel plates and shapes for construction are between 200 and 600N/mm^2, but when including wires for steel cables and cords (for automotive tires), strengths can reach 4,000N/mm^2. This indicates that steel has a wide variety of strengths compared to other materials. This is due to the distinctive nature that steel is an alloy of iron and carbon and undergoes phase transformations most importantly during cooling. By changing the carbon content and cooling rate, it is possible to produce a variety of microstructures, leading to different material characteristics. Since the theoretical strength of steel (with no defects) exceeds 10,000N/mm^2, it can be said that steel is still an emerging new material that has great potential for further strength increases.

7. Conclusions

This paper reviewed the technological advances and innovations made in steel structures and steel materials in Japan. Various steel materials that have contributed to the progress in steel structures were discussed in this paper. It was known that innovations in steel materials have enabled progress in steel structures to leap forward, and in turn challenging new steel structures has given birth to further advances in steel materials. It is without doubt that the development of high performance steels in Japan can contribute to the growing global construction market, and realize a relationship between steel structures and steel materials that results in the mutual innovation seen in Japan.