Leading High Performance Steel Plates with Advanced Manufacturing Technologies

for total cost reduction, has become increasingly intense. In concrete terms, diverse properties are now required in structural steels, including higher strength, improved weldability, and higher performance. Both precise material design technology and advanced process technology are essential for satisfying these performance requirements.

From this viewpoint, NKK Corporation recently developed and applied a completely new on-line accelerated cooling process called *Super*-OLAC® (On-Line Accelerated Cooling). This paper briefly describes the development of *Super*-OLAC, together with the development and features of new high performance steel plates produced using this technology.

2. Development of *Super*-OLAC

The key elements in the technology known as accelerated cooling are controlled rolling and TMCP (Thermo Mechanical Control Process)[1]. NKK Corporation undertook the development of accelerated cooling technology in 1985

Table 1 List of OLAC application in NKK plate mills

Cooling type	Simultaneous	Progressive	Progressive
Length (m)	44	20	20
Distance from FM *) (m)	24	53	68
Top	Pipe laminar	Curtain laminar	Corridor flow
Bottom	Spray	Suction laminar	Close suction laminar
Number of zones	-	12	22

*)FM : finishing mill

In 1985, the second OLAC unit, OLAC II, was installed at NKK's Keihin Works Plate Mill. OLAC II uses progressive type cooling equipment which performs cooling while the plate is traveling. A flat laminar cooling system, which drops a curtain-like laminar flow of cooling water on the plate, was adopted for top side cooling. For the bottom side, suction laminar cooling using a water spray with conduit pipes was adopted. This method improves the cooling function by ensuring that the water in the water tank is entrained with the moving plate. The startup of OLAC II established a supply system for accelerated cooling (TMCP) plates at both of NKK's main works, Keihin and Fukuyama.

By the beginning of the 1990s, mass production technology was required to meet rising demand for TMCP plates. A key element in this technology was more uniform cooling, aimed at minimizing the cooling strain which typically occurred with the conventional method, and thereby reducing plate re-leveling work. At the same time, product quality requirements also became stricter, as seen in the increasing need for plates with reduced strength deviations or with a narrower target strength range. Hence, improved accuracy was also desired in the cooling finishing temperature in accelerated cooling. In responding to these needs, NKK carried out basic research on cooling, which resulted in the development of a next-generation accelerated cooling process called *Super*-OLAC (**Photo 1**) based on an unprecedented, completely new concept. A commercial *Super*-OLAC process was put into operation at Fukuyama Works in 1998[3].

Photo 1 *Super*-OLAC at Fukuyama Works

Broadly classified, two forms of heat transfer phenomena and boiling occur when a heavy steel product is water-cooled (**Fig.1**). These are nucleate boiling, which occurs when direct cooling water comes into contact with the material and heat is transmitted by generation of air bubbles, and film boiling, in which a film of steam is formed between the material and the cooling water, and heat is transmitted through this steam film. The cooling capacity of nucleate boiling is the higher of the two types.

In considering the accelerated cooling process for steel plates, at the start of cooling, the surface temperature of the plate is high and cooling proceeds in the film boiling condition. However, as the surface temperature decreases, the steam film becomes unstable and local contact begins

veloped steel has won an excellent evaluation from customers, and orders in excess of 10000 tons have already been produced for large container ships for use on trunk routes, including North American and European sea lanes and others.

Fig.3 Toughness of SEGARC welded joints

3.2 High corrosion resistance plates for crude oil tanker deck plate use

In the cargo tanks of crude oil tankers, corrosion of the under side of the deck plates is an important factor limiting the service life of vessels. Based on a wealth of accumulated know-how in the field of corrosion-resistant steels, NKK carried out systematic research on the effect of alloying elements and strengthening of the function of the shop primer in preventing corrosion of steel plates for crude oil tanker deck plate use. As a result, the optimum composition balance design, using TMCP technology in combination with small additions of special alloying elements, was found to be effective in extending the corrosion protection life of the shop primer by approximately two times, while also reducing plate corrosion. Furthermore, application of a TMCP technology which includes the above-mentioned *Super*-OLAC in the manufacture of these plates made it possible to produce not only soft steel grades (YP: 235N/mm^2 class), as would be expected, but also high tensile strength steels (YP: 315, 355N/mm^2 class) with the same Ceq as at present. Using this combination of technologies, a steel plate for deck plate use, NAC5, was developed and commercialized. The new product possesses weldability equal to that of the conventional steel, together with substantially improved corrosion resistance, while minimizing cost increases. In addition to extending the useful life of deck plates (NKK's estimate: approximately 5 years), application of NAC5 to crude oil tanker deck plates makes it possible to reduce the maintenance costs required in ship repair dock work by half. As a further advantage, by alleviating corrosion of tank deck plates, the new product also reduces contamination in cargo tanks by iron rust, and thus can be expected to protect unloading pumps.

The features of the newly developed steel, NAC5, are summarized below.

- When used in combination with shop primer, NAC5 suppresses corrosion of crude oil tank deck plates, thereby extending the useful life of the vessel.
- Because NAC5 possesses weldability equivalent to that of the existing steels, it is possible to use existing welding materials. Corrosion resistance equal to that of the base material is secured in welds.
- NAC5 offers excellent economic performance, providing the maximum benefit at the minimum cost increase.

Thus, high expectations are placed on NAC5 as a material which not only reduces ship construction and maintenance costs, but also satisfies the requirements of both improved deck plate reliability and good weldability.

4. Heavy steel products for bridges

4.1 Weathering steels for coastal environments

In response to the public need for cost reduction by extending the life cycle of outdoor steel structures, beginning with bridges, NKK is developing a series of "Weathering Steels for Saline Coastal Areas", which can be applied even in coastal regions where the conventional weathering steels could not be used due to the high concentration of salt in the air. These newly developed steels not only provide dramatically improved atmospheric corrosion resistance, but also excellent weldability.

The features of the developed steels, CUPLOY 400-CLeriale3.9(s

The results of an exposure test at Miyakojima Island showed that these steels provide excellent atmospheric corrosion resistance, even with a low-Ni composition system, thanks to their optimum alloy design. Because these products also offer superior economy, use is expected to expand to a variety of applications in the future, centering on bridges.

4.2 Rust stabilizer for weathering steels, CUPTEN COAT M

Demand for weathering steels has increased in recent years in response to the heightened need for life cycle cost reduction in bridges and other steel structures. However, degradation of the scenic environment by rust streaks which occur before a stable rust layer forms and related types of pollution had become a problem. Although various rust stabilization treatments can be used to prevent rust streaks on weathering steels, the conventional methods had various problems, including the following:

- Multi-coat painting and/or special chemical conversion treatment was necessary, resulting in a complicated and expensive work process.
- Chrome compounds and similar substances were used, placing a heavy load on the environment.

In contrast, CUPTEN COAT M, which was developed by NKK, is a revolutionary rust stabilizer with the following advantages:

- As a single-layer (one-coat) treatment, CUPTEN COAT M has excellent use-related features. With NKK's proprietary technology, it is possible to combine all the functions necessary for rust

5.2 Mass production type high tensile strength steel for construction, HIBUIL385

High strength steel products are required for use in high-rise building construction in urban areas. On the other hand, the damage caused by the failure of beam end welds in the major earthquake which struck Kobe (Southern Hyogo Pref. Earthquake) in 1995 heightened the need for high performance steel products with a low yield ratio (yield point/tensile strength) and high toughness, combined with good weldability, in steel building frames. Recent years have also seen strong demand for reductions in construction costs, reflecting economic conditions.

NKK responded to these needs by developing a new plate, HIBUIL385, with a yield point lower limit value of 385N/mm^2, as a high tensile strength steel product which combines economy, earthquake resistance, and weldability. This product was approved by Japan's Minister of Land, Infrastructure and Transport under Article 37 of the Building Standards Act in April 2002. It was possible to produce this steel for the first time in the world by applying NKK's advanced TMCP technology, including the leading-edge accelerated cooling equipment on which this company prides itself.

The available size range of HIBUIL385 includes thicknesses from 19mm to 100mm. Important mechanical properties are a yield point lower limit value of 385N/mm^2 (range, 120N/mm^2), tensile strength lower limit value of 550N/mm^2 (range, 120N/mm^2), yield ratio of 80% or less, and 0 Charpy absorbed energy value of 70J or more. The chemical composition realizes a low carbon equivalent, and the specification values in the product standard are the same as those of HIBUIL355.

Currently-used steel building materials are ranked by yield point strength as 235N/mm^2, 325N/mm^2, 355N/mm^2, and 440N/mm^2. Generally, high strength steel products are used when it is necessary to lessen the weight of steel products, which can be achieved by reducing the required cross-section of members, and/or to alleviate the burden of steel frame fabrication, transportation, and erection. Considering these requirements, the strength level of steel products depends on the height of the structure, with

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Readers should note that detailed descriptions of the newly developed 610N/mm^2 class high tensile strength steel plates have been omitted here due to space limitations, but may be found in item[4)] of References.

8. Conclusion

This paper has described a next-generation accelerated cooling device, *Super*-OLAC, which was developed by NKK Corporation. This technology makes it possible to manufacture steel plates which satisfy a diverse range of recent property requirements, including welding and other construction-related requirements, while also offering outstanding cost performance. Features of NKK's high quality, high performance steel plates for respective fields have also been discussed by application, with emphasis on unique products which are manufactured using the new *Super*-OLAC technology.

It is possible that the 21st century will see demand for new types of steel plates which are not simply further extensions along existing lines of technology. Completely new design concepts and advanced manufacturing tech-