New Products & Technologies

Fire-Resistant Steel for Building Structures*

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1 Introduction

The existing construction standard law stipulates a protection of steel-structured buildings from the heat of fire by installing specified fireproofing protection, because steel materials under the heat of fire reduce their resistance. However, in addition to the poor looks of fireproofing protection, and the inadequacy of working environment, the recent shortage of skilled workers and skyrocketing construction costs have boosted strong needs for drastic reduction of fireproofing protection or even no protection at all.

In response to this need, Kawasaki Steel has developed fire-resistant steel (KSFR steel) with increased strength at elevated temperatures. KSFR steel used for building construction not only drastically reduces fireproofing protection but also makes it possible to use steel frames without fireproofing protection depending on end-use and design conditions.

This report introduces KSFR steel and an outline of the fire-resistant design principles that can be used with KSFR steel.

2 Outline of KSFR Steel

2.1 Special Feature of KSFR Steel

KSFR steel has the following outstanding features:

(1) Its mechanical properties at elevated temperatures are excellent. At about 350°C the conventional steel reduces its elevated temperature yield strength (0.2% offset yield strength) to 2/3 of its specified values at room temperature, but KSFR steel guarantees 2/3 of its specified values at room temperature up to 600°C.
(2) Its mechanical properties at room temperature are the same as those of conventional steel for building structure use.
(3) Its ductility is high because of a low yield ratio.
(4) Its workability and weldability are the same as those of conventional steel.

2.2 End-Use of KSFR Steel

Building structures that use KSFR steel can roughly be divided into two types depending on end-use and design conditions of KSFR steel; no protection type and reduced protection type.

2.2.1 No protection type

Building structures of this type are found in a relatively spacious environment with lesser amount of combustible materials, specific items being "open car parks," "atriums," "sports centers," "station buildings" and others, including portions thereof.

Fires involving these building structures are small in scale and locally confined; therefore, do not develop into fierce fires accompanied by flash-over. KSFR steel can be used with no protection.

2.2.2 Reduced protection type

Building structures of this type are found in a zone with many combustible materials with its amount beyond control, specific items being building structures other than those end-uses under 2.2.1. Fires involving these building structures are liable to become fierce and be accompanied by flash-over (1 000°C and over) to far exceed the allowable temperature (600°C) of KSFR steel, thereby requiring fireproofing protection. However, the use of KSFR steel can drastically reduce the thickness of the fireproofing protection.

2.3 Physical Properties of KSFR Steel

2.3.1 Specifications

The specifications of KSFR steel such as the chemical composition, mechanical properties at room temperature, external appearance, dimensions, shapes, mecha-

* Originally published in *Kawasaki Steel Giho*, 25(1993)1, 71-74
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nical test methods, etc. conform to JIS G 3101 or JIS G 3106. The tolerances for shapes, dimensions and weight of KSFR plate conform to JIS G 3193. Provided, however, that the plate thickness of KSFR steel is 100 mm and under. The tolerances for the shape, dimensions and weight of H-shapes conform to JIS G 3192. Provided, however, that flange thickness is 40 mm and under.

Table 1 shows the guaranteed values in elevated-temperature tensile tests on thick plates, H-shapes and columns. Besides the types shown in Table 1, KSFR steel for SMA400, SMA490 and SMA520 (atmospheric corrosion resistant steel plate) is also available.

Table 1 Specifications of elevated temperature tension test[a)]

Grade	Thickness (mm)	Test temperature (°C)	YS[b)] (N/mm²)
SS400 (FR) SM400A (FR) SM400B (FR) SM400C (FR)	≦40	600	≧157
	>40	600	≧143
SM490A (FR) SM490B (FR) SM490C (FR)	≦40	600	≧216
	>40	600	≧197

a) Elevated temperature tension test shall be performed in accordance with the requirements of JIS G 0567-1978 and its results shall be reported in mill's certification.

b) Yield strength (0.2% offset method)

2.3.2 Mechanical properties at room temperature

Table 2 shows the chemical compositions of KSFR steel. Since its C and Mn contents are low, KSFR steel has lower weld cracking sensitivity (P_{cm}) than that of conventional steels, and has excellent weldability.

Table 3 shows the tensile properties, and **Fig. 1** shows the stress-strain curve at room temperature. The tensile properties of KSFR steel are the same as those of conventional steel, while the yield ratio of KSFR steel is lower than that of conventional steels. **Figure 2** shows the Charpy impact properties of KSFR steel. The absorbed energy of KSFR steel at 0°C is sufficiently

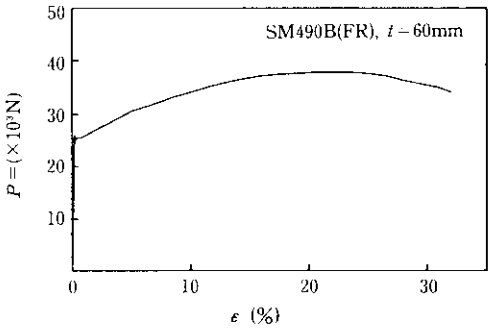


Fig. 1 Stress-strain curve at room temperature

Table 2 Chemical composition[a)] (ladle analysis) (wt%)

Grade	Thick. (mm)	C	Si	Mn	P	S	C_{eq}	P_{CM}
SM400B (FR)	16	0.09	0.30	0.81	0.005	0.003	0.35	0.17
	40	0.09	0.30	0.81	0.005	0.003	0.35	0.17
SM490B (FR)	16	0.10	0.26	0.78	0.006	0.003	0.43	0.21
	60	0.09	0.25	0.83	0.005	0.003	0.43	0.20

a) Low alloy elements may be added in order to enhance the elevated temperature tensile properties.

Table 3 Results of tension test at room temperature (C direction)

Grade	Thick. (mm)	YS (N/mm²)	TS (N/mm²)	EL (%)	YR (%)	Specimen
SM400B (FR)	16	275	454	34	60	JIS No. 1A Full thick.
		269	455	33	59	
	40	304	429	38	71	
		307	432	39	69	
SM490B (FR)	16	410	551	24	73	JIS No. 1A Full thick.
		377	558	22	67	
	60	336	492	39	68	JIS No. 4 (1/4 t)
		342	491	37	70	

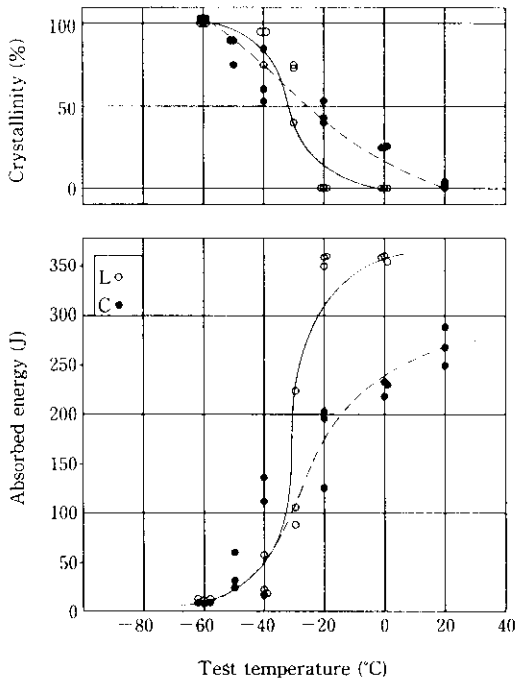


Fig. 2 Impact properties of SM490B(FR) (t = 60 mm, 1/4 t, JIS NO. 4)

high and satisfies specified value.

2.3.3 Elevated temperature properties

The temperature dependence of the elevated temperature yield strength of KSFR steel is shown in **Fig. 3**. The yield strength (YS) of conventional steel is about 2/3 of the specified values at room temperature at about 350°C, whereas the YS of KSFR steel exceeds 2/3 of the specified values at room temperature even at 600°C. In addition the tensile strength (TS) of KSFR steel is higher at elevated temperatures than that of conventional steels.

2.3.4 Jointing materials

Along with the development of KSFR steel, high strength bolting and welding materials having excellent elevated temperature properties compatible with KSFR steel were developed. An outline of the high-strength bolt is shown in **Table 4**, and the tensile properties at elevated temperatures of the bolt are shown in **Fig. 4**. The tensile properties of the deposited metal of the welded joint and the joint itself at elevated temperatures are shown in **Fig. 5**. A joint made of these materials has an elevated temperature strength equal or superior to that of the base metal, assuring its safety in a fire.

Table 4 Tip shear off type high strength bolt for KSFR steel

Class according to mechanical properties	Code	Constituting parts	Grade according to mechanical properties of constituting parts	Materials
No. 2	F10T (FR)	Bolt	F10T	KF10T (FR)
		Nut	F10	KF10T (FR)
		Washer	F35	S45C

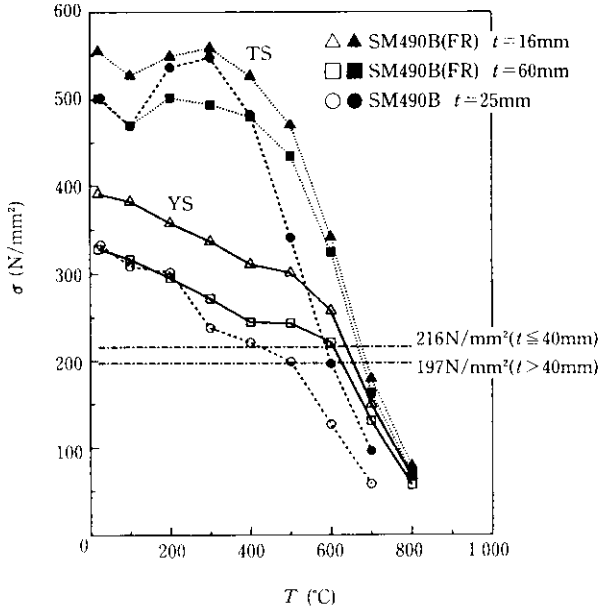


Fig. 3 Results of tension test at elevated temperature

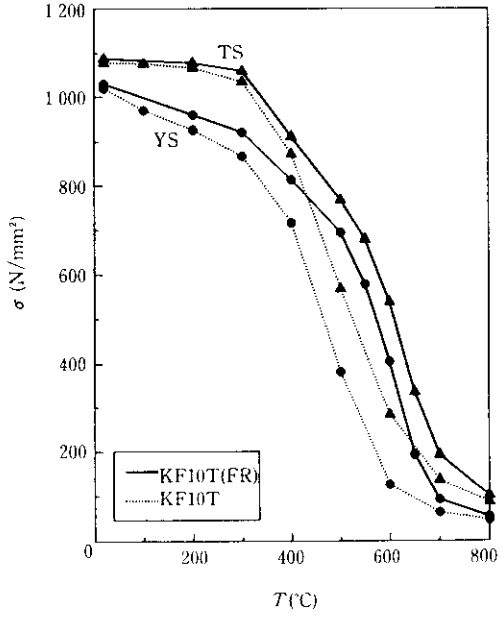


Fig. 4 Elevated temperature tension test results of tip shear off type high strength bolt's material

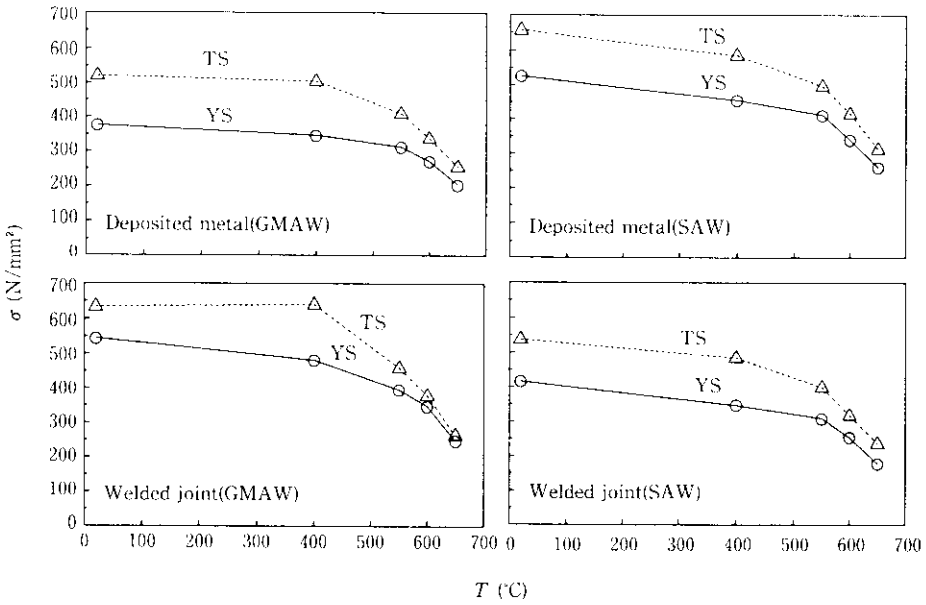


Fig. 5 Results of tension test of deposite metal and welded joint at elevated temperature

3 Fire-Resistant Design for KSFR Steel

When using KSFR steel for a building structure, it is necessary to confirm the fire resistance of individual building according to the "Fire-Resistant Design Guidelines for Fire-Resistant Steel" (Building Center of Japan) based on the new fire-resistant design method. This design method is a part of the "Development of a Design System for Building Fire-safety" in a project carried out by the Ministry of Construction during the period from 1982 to 1987. The guideline includes the following three major design methods in the results developed by this project.

(1) Prediction of fire behavior
(2) Prediction of steel temperature
(3) Prediction of frame deformation

After confirming the fire resistance performance of individual buildings through the above-mentioned analyses and obtaining a fire safety performance appraisal certificate from the Building Center of Japan, it is necessary to obtain a Construction Ministry certification that the building using KSFR steel under articles 38 and 67-2 of the Building Standard Law has the same fire resistant performance as that of a fire-resistant building.

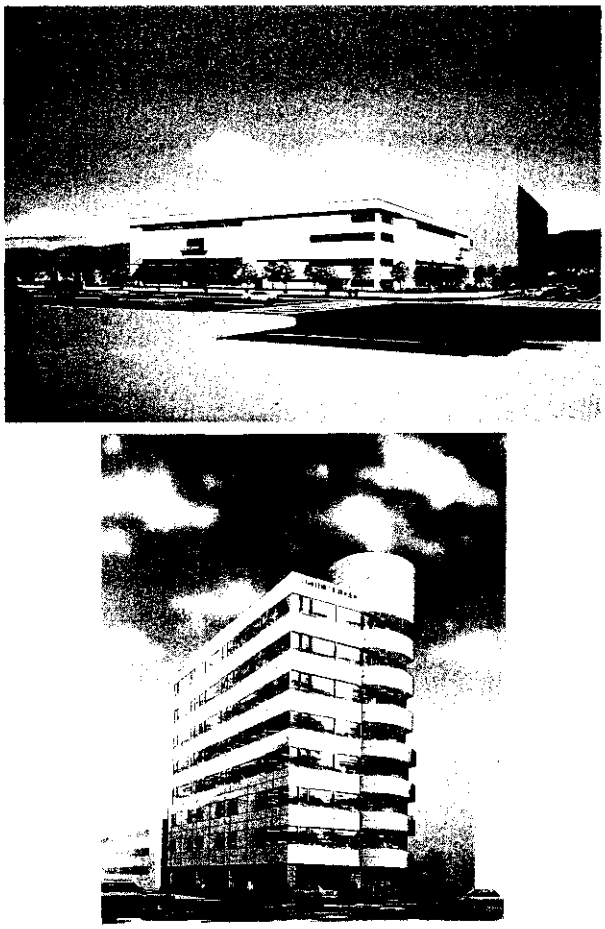
4 Application Examples of KSFR Steel

Examples of buildings to which the Kawasaki Steel has already applied KSFR steel are summarized next (**Photo 1**).

(1) Rokko Factory of Shinwa Package Corp.
This factory mainly performs packaging of plant products and manufacturing and processing of packaging materials made of steel. The factory owns office and rack warehouses. The use of KSFR steel for this factory made it possible to eliminate fireproofing protection for the flame structure for the packaging yard which have no combustible materials, and to drastically reduce fireproofing protection for the rest of structures.
(2) Tokyo Head Office Building of Kawasaki Setsubi Kogyo Co., Ltd.
The use of KSFR steel for the beams of this office building made it possible to drastically reduce fireproofing protection.

5 Concluding Remarks

The development of the new fire-resistant design method made it possible to evaluate building structures using KSFR steel in term of fire-resistant performance and has also confirmed the virtually equal level of workability of KSFR steel to that of conventional steels. All this proves that KSFR steel has reached the stage of practical serviceability in design and execution both. Considering the notable needs for drastic reduction in fireproofing protection and possibly its elimination, KSFR steel has great expectations from all users. To meet all this expectation, Kawasaki Steel has determined to make further active development of effective usage of KSFR steel so as to realize building structures that can fully utilize excellent design features of steel structure itself.



Upper: Shinwa Package Corp. Rokko Factory
Lower: Kawasaki Setsubi Kogyo Co.Ltd. Tokyo Branch Office

Photo 1 Example of application of KSFR steel

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