CRYOGENIC STRUCTURAL STEELS FOR ACCELERATOR SUPERCONDUCTING MAGNETS AND THEIR APPLICATION

K.NOHARA, U.NISIIKE, T.KOBAYSHI,and T.AKITA*
(Kawasaki Steel Corp; *Akita Fine Blanking Co. Ltd.; Japan)

1. INTRODUCTION

Large scale superconducting magnets for huge colliding particle accelerators consist a variety of essential components. Among them cryogenic structural materials (steels) are employed as collars, center/end yokes and beam pipes. Coping with the requirements for both non- and ferro-magnetic characteristics,the magnetically opposite types of steels have been newly developed and applied to R/D and practical uses. [1]

2. DEVELOPEMENT OF STRUCTURAL STEELS

2.1 Non-magnetic Steel (KHMN)

Targetting non-magnetizm (low permeability, μ), low thermal expansivity, β, and (high) controllable strength, σ, at ambient and cryogenic temperature ranges for the use of collars, end yokes (voids) and beam pipes, a new high Mn steel (KHMN) was developed to be the follwing chemical compositions: 0.1C-28Mn-7Cr-1Ni-0.1N-0.06V.

The steel is featured by high content of Mn to guarantee much less dependence of μ on both temperature and deformation. The strength can be specified with the final temper cold rolling.

Table 1 lists up the physical/mechanical properties of temper rolled KHMN corresponding to the requirements of the SSC magnet collar. Considerably low values of μ and β are exhibited compared with AISI316LN stainless steel.

It was found in Fig.1 that the relations between the Néel temperature, TN, and either μ or β can be shown by smooth curves and that TN is formulated with Mn and C contents, which is properly employable to the KHMN alloy designing.[2]

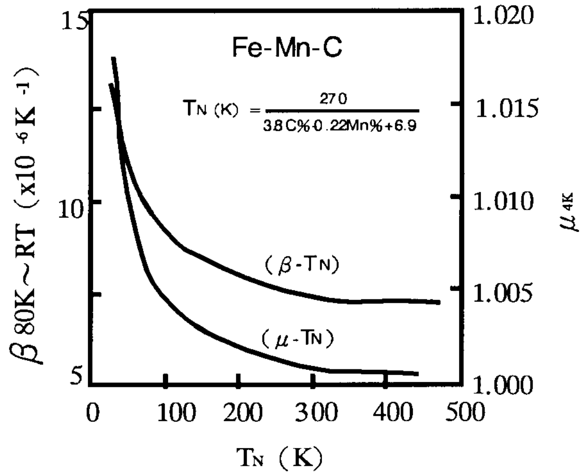

Fig. 1 Relation between thermal expansivity, β or magnetic permiability, μ, and the Néel temperature, TN, that is formulated by the equation herein.

Table 1 Properties of non-magnetic steel (KHMN) (plus AISI 316LN) (1.5 mmt cold rolled)

Items			Target (SSC)		KHMN		316LN(Ref.)	
			RT	4K	RT	4K	RT	4K
	Magnetic permeability	Absolute value, μ	≦ 1.002		1.0009	1.0010	1.008	1.017
		Deviation, △μ	≦ 0.0005		± 0.0002	± 0.0002	± 0.002	± 0.005
	Thermal contraction	Coefficient (80 ～ 300K,K -1)	equal to or less than those of iron		7.5 × 10 -6		7.5 × 10-6	
		Displacement (4 ～ 300K,mils/in)			1.7		3.1	
	0.2% proof strength		≥ 630	≥ 1200	690	1500	580	1420
	Tensile strength		(as large as possible)		830	1720	880	2250
	Total elongation				33	29	40	34
	Charpy impact absorption energy (J)				274	135	290	120

* Thermal contraction of iron : 9.2 × 10 -6/K,

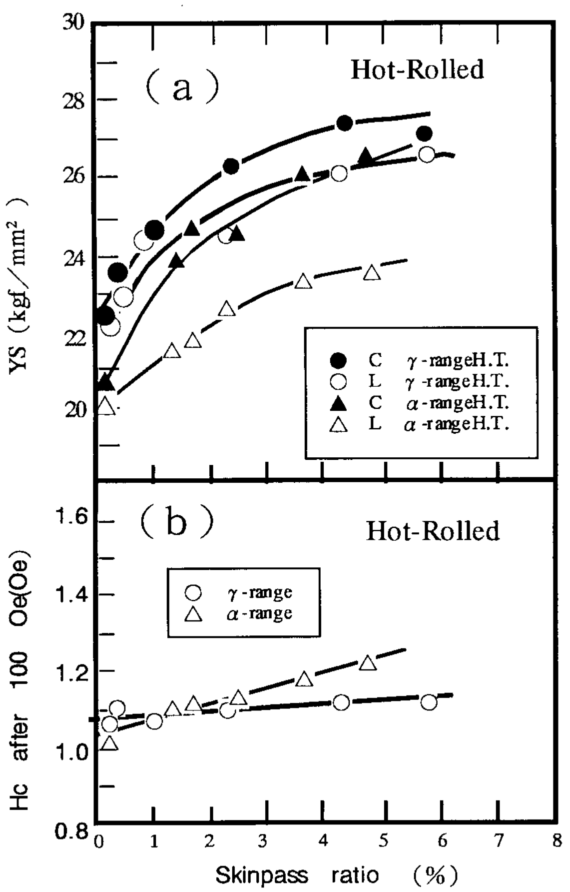

Fig.2 Relations between yield stress (YS) or coercive force (Hc) and skin pass ratio of 6.3 mm thick hot-rolled EFE heat treated at γ or α - range temperatures (without annealing).

2.2 *Ferro-magnetic Steel (EFE)*

For the purpose of preparing the shielding material for center yokes in particular owing low coercive force, Hc, high μ and rather high (ie. hardness. Hv), a new ultra low C steel (EFE) was innovated to have 0.0011C-0.0015N, realizing much smaller Hc. The higher values of σ/Hv are available by the final skinpassing to show only slight deterioration of magnetic properties thanks to ultra-low C composition.

The examples of 6.35mm thick hot rolled products for the RHIC magnet showed the following results : Hc (100 Oe applied)=1.1 (RT) and 1.1 (4K), μ (1 Oe applied)=3200 (RT) and 3500 (4K), YS=245MPa experimentally and practically. Figure (RT) and RB=25 (RT). It is strongly noticed in Fig.2 that the final skinpassing is more influential upon strength (yield stress,YS) than Hc, and that YS changes differently in heat treatment ranges (- γ and α phases) and the directions from rolling process (L:rolling direction, C: transverse direction).[3]

3. APPLICATION OF DEVELOPED STEELS

3.1 *Fine-Blanking*

In order to avoid the AC loss the cold mass of a superconducting mgnet is of a lamination structure. Resultantly a great number of collars and yokes are to be fine-blanked, followed by pairing, moduling, stacking, tooling and final fablicating of a magnet. Hence the fine-blanking is important in view of the steel used, flatness, dimensional accuracy, mass-productivity, cost performance, etc.

Figures 3 and 4 show the flatness changes of fine-blanked KHMN collars and EFE yokes, respectively. In case of KHMN the final levelling for flatness correction greatly affects that of a collar product, while EFE gets free from a large grade of flatness by the employment of fine-blanking. This is mainly because of difference in strength and metallurgical phases of both steels. [4]

3.2 *Magnet Performance*

The developed KHMN and EFE have been used for a variety of accelerator projects as a magnet component, experimentally and practically. Figure 5 is an example of R/D magnet performance test rest result. [5]

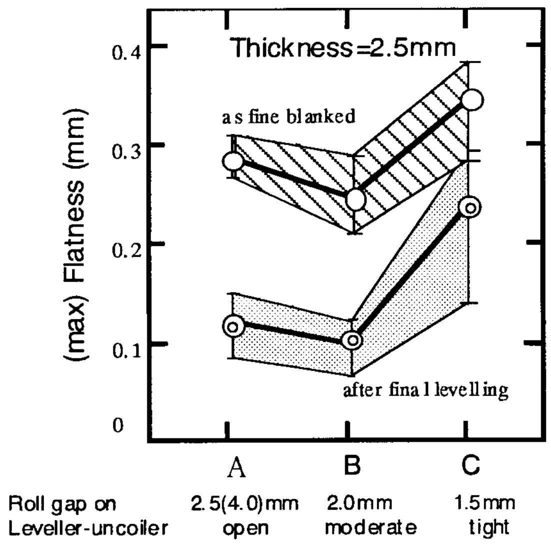

Fig. 3 Flatness of fine-blanked KHMN collars before and after final correction levelling

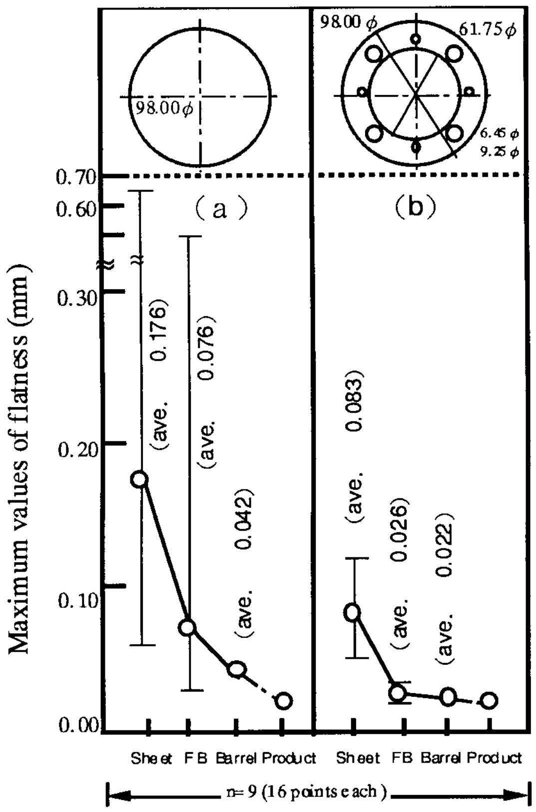

Fig. 4 Flatness measurement at each process of fine-blanking (FB) of 6.35 mm thick EFE sheets for (yoke) products

The change in sextupole normal error component, b2, with electric current up to 6600A, illustrated in the figure was measured on SSC R/D magnets, where the collar materials used were KHMN and modified AISI 316LN stainless steel. The values of b2 associated with both steels show a different tendency : b2 with KHMN increases smoothly as the current grows larger, leading to a favorable magnet operation, whereas b2 with the stainless steel presents a minimum value around 3500A. This is probably due to the thermal contraction difference between both steels toward that of iron yoke, resulting in the contact of stainless steel collar with iron yokes to be deleterious to the operation of a magnet. The RHIC dipole magnets quench tests were carried out using 13 magnets. No training was achieved in most cases beyond 30% margin quench current (6500A), except for just a single magnet when it was subjected to thermal cycle. These are all actual magnets mounted with 6.35mm thick hot-rolled EFE as yokes to be now installed in the RHIC tunnel.[6]

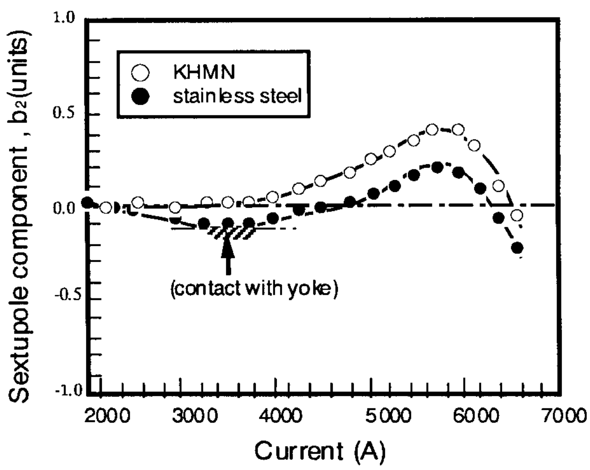

Fig. 5 Change in sextupole error component with current in dipole small magnets with KHMN and stainless steel collars (SSCL)

4.CONCLUSION

The cryogenic structural steels, non-magnetic high Mn (KHMN) and ferro-magnetic ultra low C (EFE), were newly developed. Featured are controllable strength and low expansion in the former, and also manageable strength and low coercive force in the latter. Both are favorably employed as cold mass collars and center/end yokes of accelerator superconducting magnets for R/D and practical purposes by taking care of fine-blanking process. There cold be a possibility of the steels and fine-blanking technology to be applied to the on-going LHC project.

*The works have been performed in collaboration with BNL, SSCL, FNAL, KEK and CERN.

REFERENCES

[1] T.Shintomi, H.Ishimaru, Y.Unno, Y.Arai, Y.Watase, K.Amako and T.Kondo: J.ISIJ, 78 (1992).

[2] K.Nohara, K.Okumura, S.Sato and H.Sasaki: Super Collider 4, (1992).

[3] K.Nohara, U.Nishiike, K.Suzuki, T.Mori, K.Okumura,H.Terami and H.Sasaki: Super collider 4, (1992).

[4] K.Nohara, S.Sato, K.Okumura and H.Sasaki: ICEC-15, (1994).

[5] Okumura and H.Sasaki: ICMC, (1995).

[6] A.Greene, P.Dent and C.Hallquist: Superconductor Industry, (1995).