Recent Progress of Ferrous Materials for Automobile in Japan

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Hyper extra deep drawing steel grade produced with IF steel, IF based HSS, Dual Phase steel, TRIP steel, Galvannealed IF steel, Anti corrosive Cu bearing steel sheet, IF based metal coated steel sheet for fuel tank eliminating Pb and special steels for spring, gear and crank shaft are deseribed in terms of production and application technology.

Keywords: material, automobile, steel

Recent trends in ferrous automotive materials in Japan are for weight saving relating with the reduction of CO_2 emmission and the reduction of manufacturing cost in steel suppliers and steel users.
Some topics are described in the following.

1. PRODUCTION OF IF STEEL IN JAPAN

Fig.1 shows steel grades for deep drawing in terms of Lankford value and total elongation in Japan. Customers' requirements for deep drawability have been so raised that Hyper EDDQ grade is produced by advanced IF steel technology.

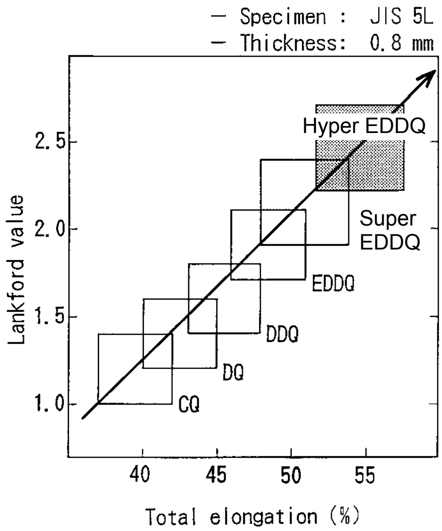

Fig.1 Deep formable steel sheets

It is considered that the annual production of IF steel in 1999-2001 in Japan was 6-7 million tons and the transition of steel grades in IF steel in this decade is shown in Table 1.[1)] It is obvious that the production of Zn coated one and HSS (High Strength Steel) are increased in contrast to that of cold rolled one. In the case of HSS, IF 35K BH steel grade has been increased at the most. The tendency seems to last further because of the demand from automobile customers. The production of as hot rolled grades has been none, but because their thin gauged ones are becoming practical by continuous hot rolling technology. When hot dip galvanizing subsequent to the hot rolling is applied, a new steel grade would have an opportunity to appear in the market.

Year	HSS (%)	Cold Rolled (%)	Zinc Coated (%)
1993	5.3	55.0	39.7
1994	5.3	55.3	39.4
1995	5.2	55.7	39.1
1996	5.5	53.3	41.2
1997	5.5	52.6	41.9
1998	6.1	46.1	47.8
1999	8.9	31.2	59.9
2000	10.7	31.0	58.3
2001	11.6	28.3	60.1

Table 1 The Transition of Steel Grade in IF Steels in Japan[1)]

41st Rolling Seminar-Processes, Rolled and Coated Products October 26 to 28, 2004 Joinville-SC-Brazil,

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2. IF STEEL PRODUCED BY THIN SLAB CASTING AND DIRECT HOT ROLLING PROCESS

CSP and MDH process are actually running in many countries, however, lack of the chance for transformation and large reduction during hot rolling seem to be disadvantageous for improving some properties such as notch toughness, deep drawability and so on in metallurgical sense. When steel matrix is converted to be interstitial free, for example, the disadvantage could be saved for deep drawability. Five kinds of specimen were cast into thin slab which thickness was 50 mm, followed by direct hot rolling, when the thickness was reduced to 5 mm. Their chemical compositions are shown in Table 2. After cold rolling with 80% reduction continuous annealing and batch annealing were applied. The annealing conditions were 880°C × 1 min - 350°C × 5 min and 720°C × 4 hrs respectively.

Mechanical property measured after temper rolling with 0.8% reduction is summerized in Table 3. Microstructure of hot rolled steel sheet turns finer when Nb is added as shown in Fig.2(C,D) and it can be considered that the mechanical property is improved to the level of DDQ grade produced with Al killed steel and treated by conventional process.

	C	Si	Mn	P	S	Al	Nb	Ti	B	N	(Nb+Ti/C+N)at	(Nb/C)at
A	0.0021	0.012	0.10	0.010	0.007	0.032	0.007	0.024	0.0001	0.0030	1.48	0.43
B	0.0019	0.006	0.10	0.010	0.007	0.029	0.006	0.027	0.0017	0.0035	1.54	0.41
C	0.0018	0.014	0.09	0.010	0.007	0.029	0.014	0.001	0.0018	0.0028	0.49	1.00
D	0.0023	0.016	0.10	0.010	0.007	0.029	0.059	0.001	0.0018	0.0029	1.64	3.31
E	0.0016	0.017	0.11	0.011	0.009	0.034	0.020	0.001	0.0001	0.0036	0.60	1.61

Table 2 Chemical composition of steels (mass%)

Continuous Annealing

	YS (Mpa)	TS (Mpa)	El (%)	n value	Mean r	Compo.
A	128.7	256.3	49.9	0.22	1.65	Ti(24)
B	122.3	253.0	51.8	0.27	1.49	Ti(27)+B
C	136.7	258.7	51.1	0.27	1.63	Nb(14)+B
D	143.0	292.7	44.5	0.25	1.64	Nb(59)+B
E	146.6	266.9	50.9	0.27	1.53	Nb(20)

Batch Annealing

	YS (Mpa)	TS (Mpa)	El (%)	n value	Mean r	Compo.
A	161.0	319.3	37.7	0.22	1.26	Ti(24)
B	217.3	332.0	33.5	0.18	1.34	Ti(27)+B
C	168.3	303.7	44.3	0.24	1.13	Nb(14)+B
D	203.0	328.7	41.7	0.22	1.52	Nb(59)+B
E	162.7	304.0	48.1	0.23	1.64	Nb(20)

Table 3 Mechanical Properties of Specimen

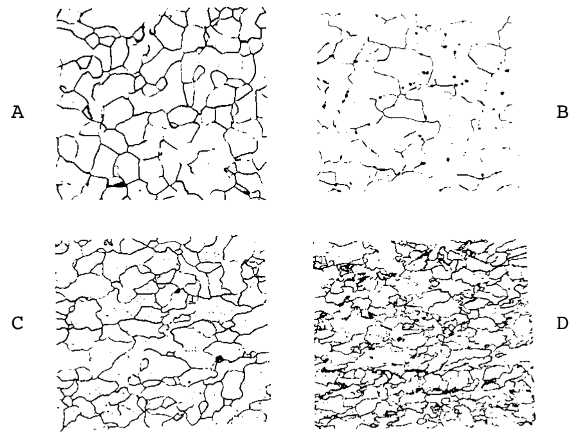
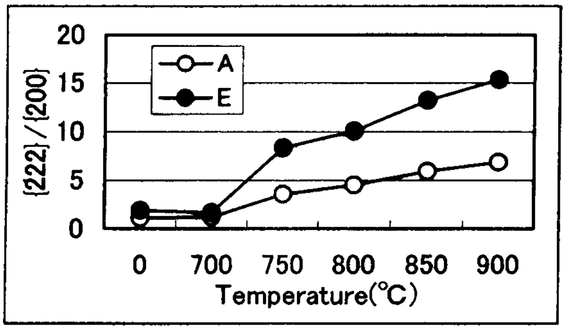


Fig.2 Micorostructure of Hot Rolled Steel

{222} oriented grains preferentially grow during recrystallization in the case of Nb added specimen E as shown in Fig.3, which depends on the inhibition of preferred nucleation of {110} recrystallized grains and the consumption of {100} recovered grains.

Fig.4 shows the difference in the transition temperature between ductile and brittle fracture during secondary working of specimen A and E. Continuously annealed specimen showed better ductility more than batch annealed one by keeping grain boundaries not so clean due to shorter annealing time and rapid cooling.



Specimen A : 0.024% Ti, 0.007% Nb
Specimen E : 0.020% Nb, 0.001% Ti

Fig.3 Change in textures of specimen A and E during annealing

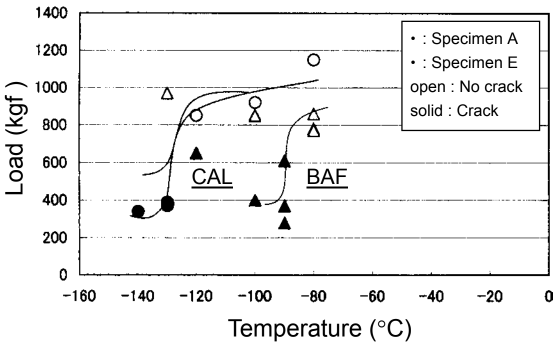


Fig.4 The relation between load and cracking, A and E are specimen No. in Table 2, CAL and BAF are continuous annealing and batch annealing respectively.

3. NEW IF BASED HSS

Urabe[2)] showed a distinguished microstructure in IF based steel in Fig 5, which contains comparatively higher carbon and Nb as shown in Table 4.
At earlier stage of annealing, Nb exists as fine NbC precipitates at ferrite grain boundaries. As the annealing goes on, the precipitates tend to grow and reduce their number by the grain boundary diffusion of Nb and C, and the pinning effect against the grain growth is unlocked by the Ostwald ripening mechanism. Fig 6 shows the white depleted zone along grain boundary which gives lower yield strength and good resistance against cold working embrittlement to products.

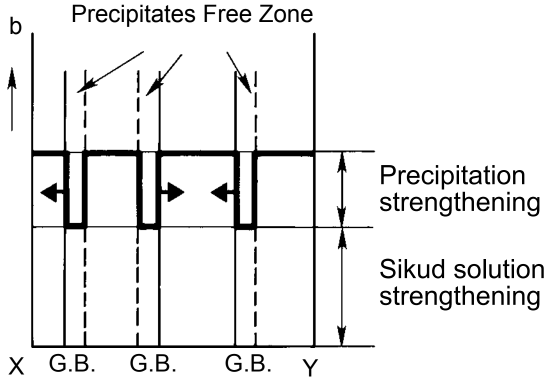


Fig. 5 Schematic diagram exhibiting the hypothesis with respect to the mechanism of the lower yielding in Steel B strengthened by the solid-solution and fine niobium carbides with PFZ[2)].

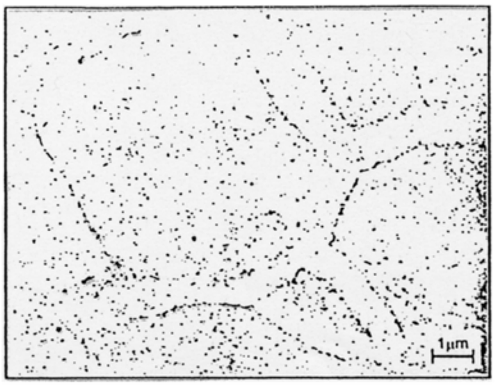


Fig. 6 TEM image with replica of the distribution of niobium precipitates in the annealed sheet at 850°C of Steel B. (High Nb-High CIF)[2)]

Type	C	Si	Mn	P	S	sol.Al	N	Nb	Ti
Developed	0.0066	0.01	0.35	0.020	0.007	0.056	0.0018	0.093	-
Reference	0.0023	0.01	0.45	0.056	0.007	0.052	0.0020	0.021	0.022

Table 4 Chemical composition of steels for mill trial. (mass%)[2)]

4. TRIP STEEL

TRIP (Transformation Induced Plasticity) steel is found to have the most excellent balance between tensile strength and elongation as shown in Fig 7, in which the elongation[3] of TRIP reaches to 30% at 980 MPa of tensile strength. $\bar{r}$ value of TRIP is approximately 1.0, however, TRIP has excellent deep drawability like mild steel[4] as shown in Fig 8. This behavior was found to be based on the tension or compression dependency of martensitic transformation at flanging area and punch shoulder of cup[5] as shown in Fig 9. When austenite transforms into martensite, volume expansion takes place, and the transformation is suppressed by the compression at flanging area. Hence, flanging area leaves soft and metal flow can easily be supplied to die cavity from flanging area. On the contrary, martensitic transformation can be accelerated by the tension at punch shoulder, and the part is strengthened by hard martensite introduced by the transformation. This behavior is based on a new conception to control deep drawability, not depending on the effect of crystallographic texture. Recently, Nb addition was found to increase the volume of retained austenite in hot rolled[6] or hot and cold rolled[7] TRIP steel as shown in Fig 10(1) and Fig 10(2). Nb makes austenite grains fine during hot rolling, and many ferrite grains are formed at austenite grain boundaries which accelerate carbon concentration in retained austenite.

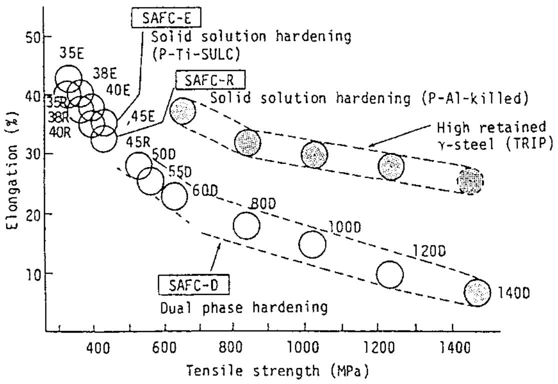
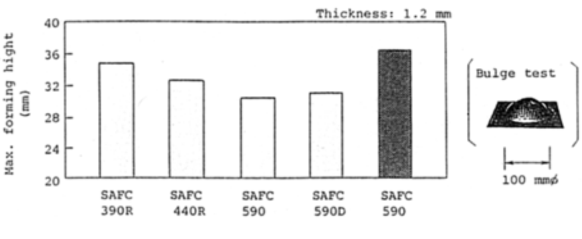


Fig. 7 Tensile strength-Elongation balance in various High Strength Steels



Formability of TRIP-HSS in bulge test

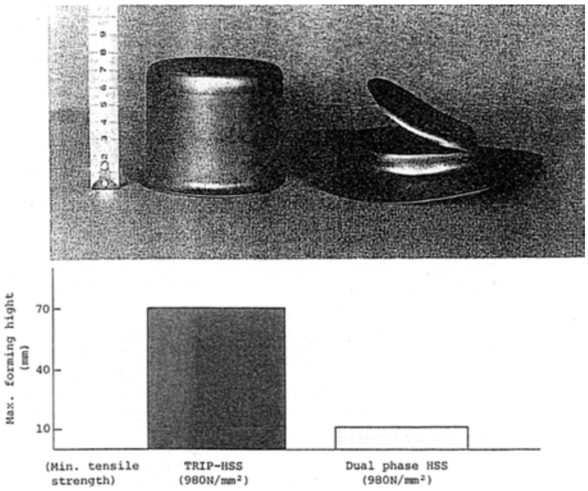


Fig. 8 Formability of TRIP-HSS in cylindrical drawing test[3)]

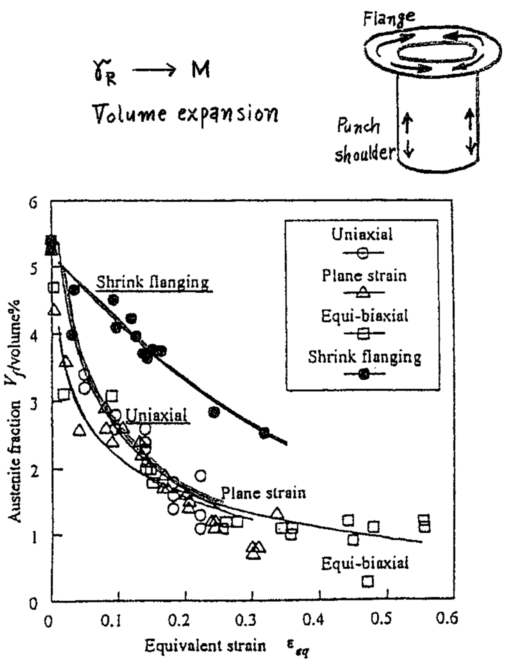


Fig. 9 Changes in volume fraction of austenite vs. equivalent plastic strain under the four deformation conditons[5)].

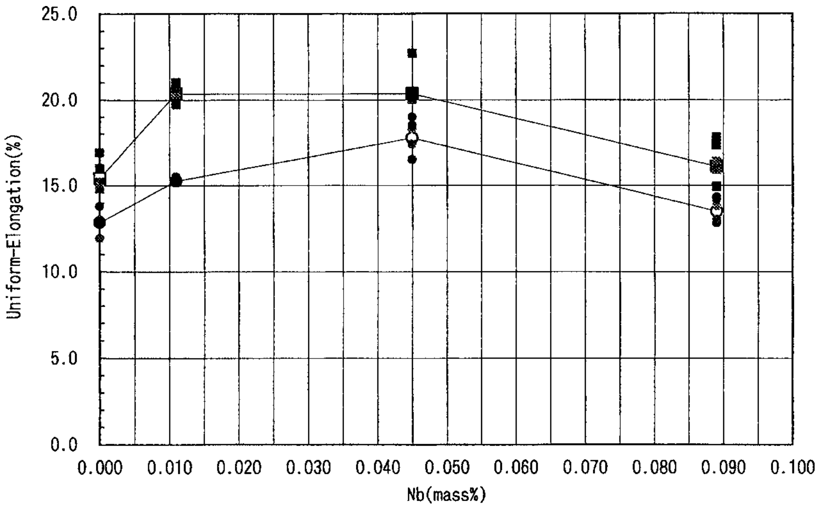


Fig. 10(1) Effect of Nb Addition on Uniform-Elongation.[6]

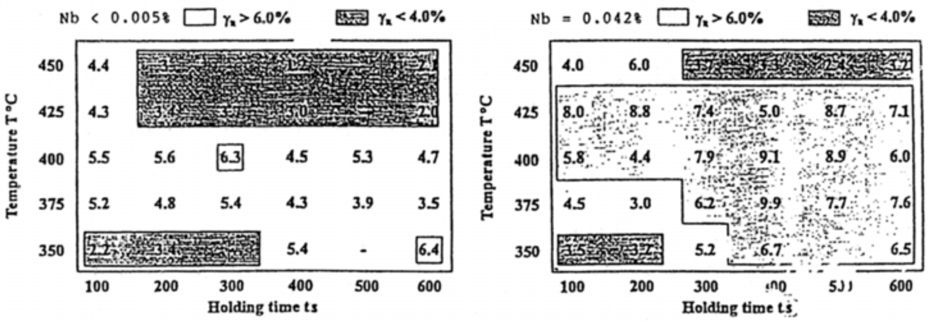


Fig. 10(2) The effect of Nb addition on the formation of γ R during bainitic transformation.[7]

5. ANTI CORROSIVE STEEL SHEET CONTAINING Cu AND P

According to NSC's data in Fig.11, Cu is very effective to improve anti corrosion property of steel sheets under the cooperation with P. Recently Shibata[8] pointed out that Sn and Cu cooperate to accelerate cracking during hot rolling, however, slab reheating temperature higher than 1,200°C tends to avoid the cracking as shown in Fig.12.

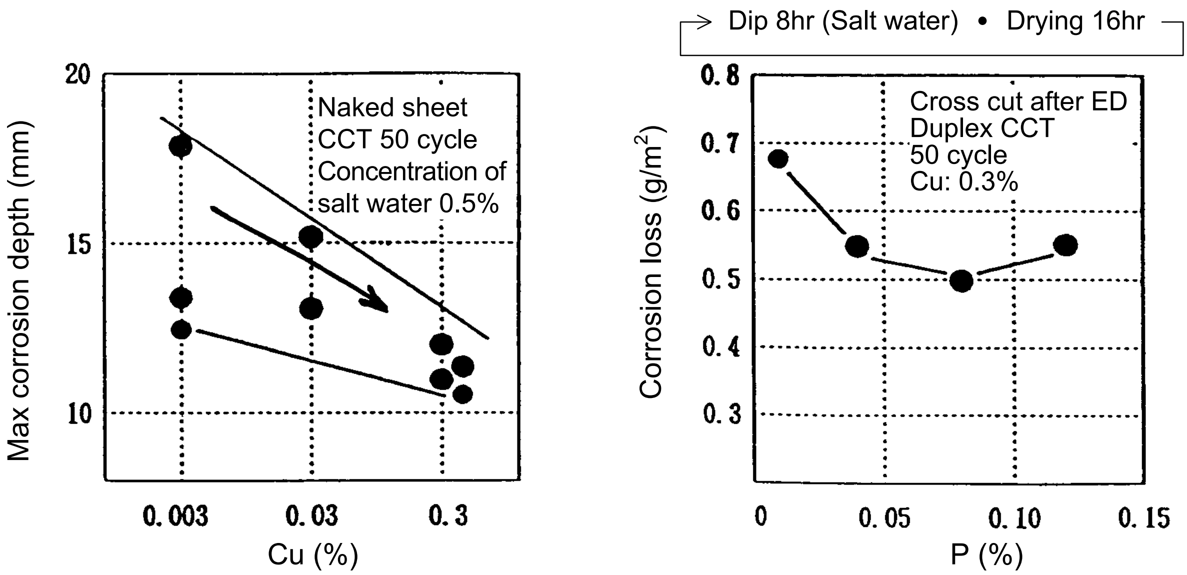


Fig.11 The effect of Cu and P on the corrosion resistant property

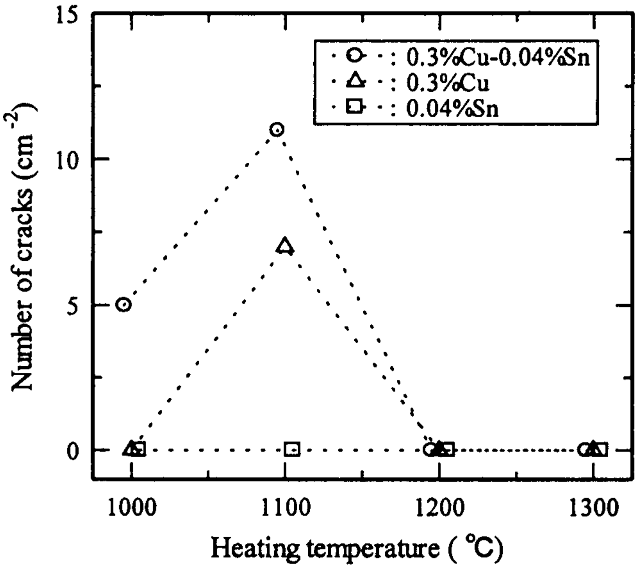


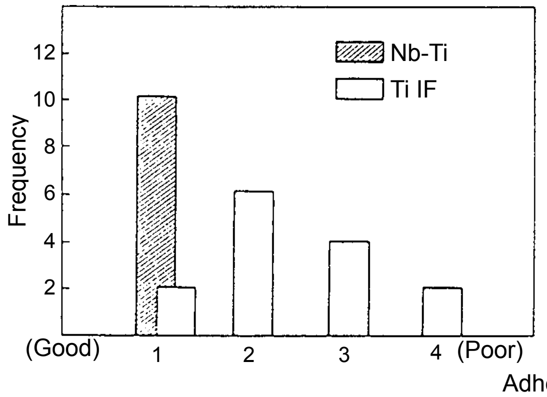
Fig.12 Effect of heating temperature on the surface cracking caused by Cu and Sn[8)]

6. ADHESION PROPERTY OF ZINC COATED LAYER ON GALVANNEALED IF STEEL SHEET

Galvannealed Nb-Ti IF has better adhesive property of coated zinc than that of Ti IF as shown in Fig.13[9)]. In general, Al in zinc bath concentrates at the interface between molten zinc and steel matrix, forming Fe-Al-Zn intermetallic phase which inhibits the formation of Fe-Zn alloying layer. Meshii[10)] reported that the composition of Fe-Al-Zn intermetallic phase is Fe_2Al_5 mainly in the case of Ti IF and Ti-Nb IF However, Al tends to diffuse out easily through grain boundaries of Ti IF, because Ti takes out C and N so completely followed by making the grain boundaries pure and vacant. Hence, the local contact between molten Zn and Fe matrix happens to form Zn-Fe intermetallic compound like Γ phase at the grain boundaries with ease. Yamada showed the difference of alloying layer between Ti IF and Nb-Ti IF in Fig.14.[9)]

In the case of Nb-Ti IF, sound and uniform Fe-Al intermetallic alloying layer is formed which improves the adhesive property of coated zinc.

Gasoline tank has been changed to the more complicated in shape because the space in which the tank should be installed has turned to the more narrowed and the more complicated because of weight saving and down sizing of cars. Gasoline tank is generally coated with terne metal, which



(Coating weight: 110•140 g/m^2,
Fewer Al in bath: 0.08%)

Fig.13 The effect of chemical composition on the adhesion of zinc coated layer.[9)]

tends to deteriorate formability of steel sheets. In that occasion IF steel is very useful to be formed to the complicated shape, when metallic coating is applied.

Recently Nippon Steel Corp. developed a new IF based steel sheet for gasoline tank, which is coated with Sn-Zn metals eliminating Pb in terne sheet from environmental view point. This one is more superior in formability and anti-corrosion property to the conventional one as shown in Fig.15 and Fig.16 respectively. IF steel happens to cause a trouble called cold working embrittlement which is a kind of grain boundary fracture. But niobium

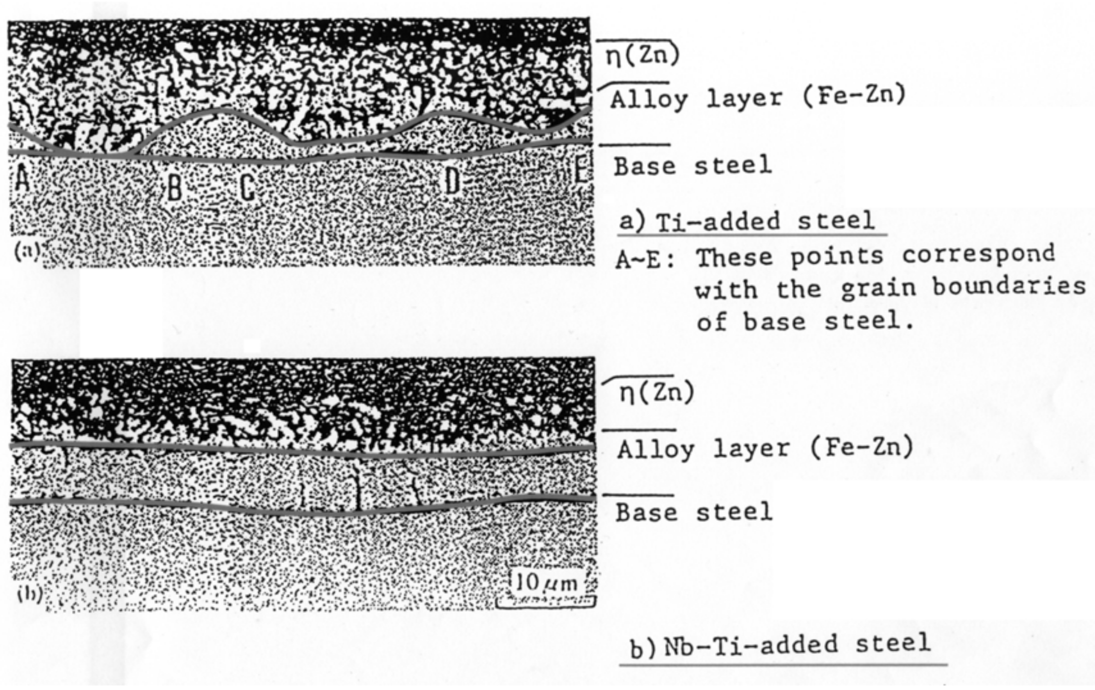


Fig.14 Alloy layer in the middle of growth. [9)]

containing IF steel with boron addition can stabilize the grain boundary, and the transition temperature between ductile and brittle fracture can be lowered to approximately -60°C as shown in Table 5. B, Nb and uncombined C atoms would stabilize grain boundary followed by decreasing the transition temperature.

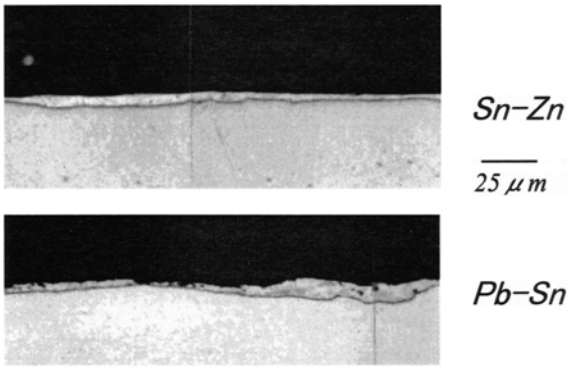
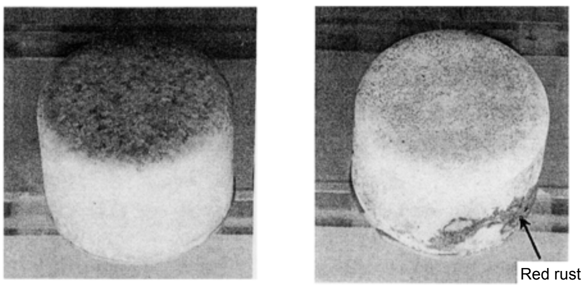


Fig.15 Damage of coated layer after draw-bead test



Sn•9%Zn Terne sheet

Fig.16 Anti-corrosion property of IF based Sn-Zn coated steel sheet.
Corrosive atmosphere is composed of formic acid and acetic acid solution containing chlorine.

	Nb*=0.023%	Ti=0.050%	Nb=0.024% Ti=0.011/12%
B=0 ppm	•	•	-5°C
B=14/15 ppm	-60°C	-25°C	-40°C

Note : C=22•30ppm

$$* \frac{C}{Nb} = \frac{12}{93} = \frac{25ppm}{194ppm}$$

Table 5 The effect of Nb, Ti and B addition
on the transition temperature of IF steel sheet

7. SPRING STEEL

7.1 VALVE SPRING STEEL

The steel is required to be guaranteed against the stress brought by repeated cycles more than 100 millions. Mainly oil tempered Si-Cr steel is used, and 2% Si steel was developed to improve the resistance to tempered softening as shown in Table 6.
It is necessary for valve spring to improve fatigue property by lowering the melting temperature of inclusions which brings about the plasticity during hot rolling. The chemical composition of the inclusion is shown in Fig 17.[11)]

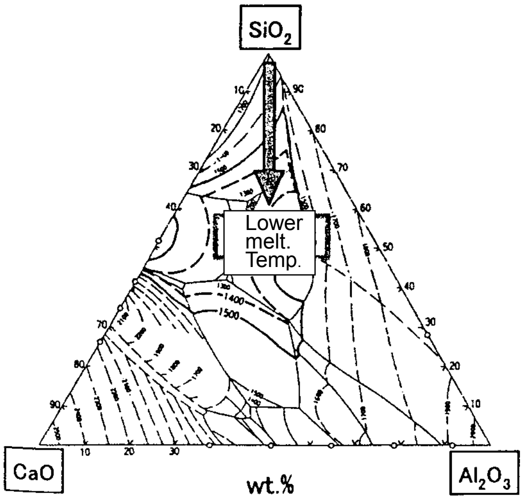


Fig. 17 Lowering the melting temp. by changing the chemical composition of inclusions[11)]

7.2 SUSPENSION SPRING STEEL

Higher Si steel as much as 2% (SUP7) was developed in 1980's to improve wear resistance property of steel. By adding V and Nb to SUP7, max. shear stress is increased to approximately 1,100 N/mm^2.
In corrosive atmosphere, fatigue property is deteriorated when the hardness is more than HRC50, Ni and Cu addition was found to be effective to eliminate corroded pits which become origins of fatigue crack.
Max. shear stress more than 1,300 MPa is required as a new product in very near future.

8. GEAR STEEL

As for the chemical composition of gear steel, lowering Si is useful for reducing the oxydizing layer at grain boundary, Ni and Mo are useful for improving quenching property and Nb is useful for grain refining as shown in Table 7. Generally speaking, cost and property of steels are in trade-off, the suitable selection for chemical composition and required property is necessary to individual condition when actually produced.
Nb is very useful for inhibiting the grain coarsening of austenite during carburization as shown in Fig 18[12).
B added steel is used for increasing quencheability as shown in Table 8, in which Si and Mn contents are adjusted to meet the same quencheability with SCr420. Ti is used for killing nitrogen.
Nb was found to increase grain coarsening temperature of austenite so remarkably as shown in Fig 19.
With the addition of Nb as much as 0.05%, the temperature can be raised about 100 K. Grain coarsening temperature is defined as the one at which the ratio of coarser austenite more than G.S No. 4 is 5%.

	C	Si	Mn	Ni	Cr	Mo	V	Nb
2%Si	0.59	1.93	0.85	0.25	0.91	-	0.	-
	0.63	1.95	0.77	-	0.71	-	0.08	-
	0.73	2.01	0.75	-	1.02	0.22	0.37	0.22

Table 6 Examples of high strength steels for valve spring

Steel	Prev. Abnormal carburize. zone	Boundary strength	High Strength			cost	Chemical composition
			Fatigue tooth root	Impact tooth root	Fatigue tooth surface		
A	•	-	•	•	-	•	Low Si-1.0 Cr-0.4 Mo
B	•	•	•	•	•	•	Low Si-Low Mn-0.6 Cr-1.0 Mo-0.03 Nb
C	•	•	•	•	•	•	Low Si-Low Mn-1.0 Ni-0.25 Cr-0.75 Mo-0.03 Nb
D	•	•	•	•	•	×	Low Si-Low Mn-2.0 Ni-0.8 Mo-0.03 Nb Cr

•The most effective •Effective
•Less effective ×Not effective

Table 7 Examples of high strength gear steel

Steel	C	Si	Mn	Cr	s-B	s-Al	N	Ti	Nb
B-added	0.18	0.08	0.50	1.05	0.0015	0.030	0.009	0.040	0•0.20
SCr420	0.19	0.24	0.82	1.12	-	0.029	0.012	-	-

Table 8 Chemical composition of B, Nb added steels (mass%)

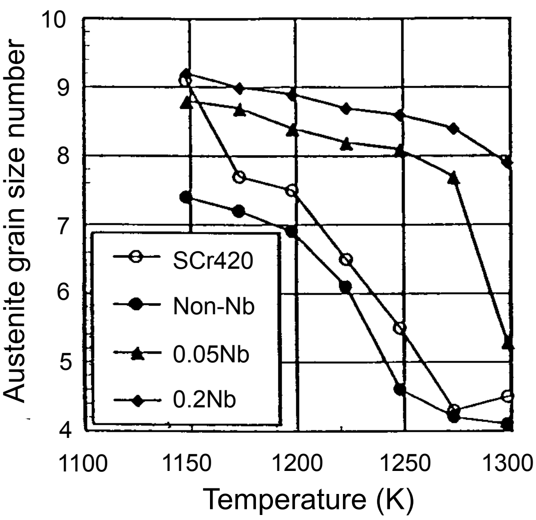


Fig. 18 Relationships between heating temperature and austenite grain

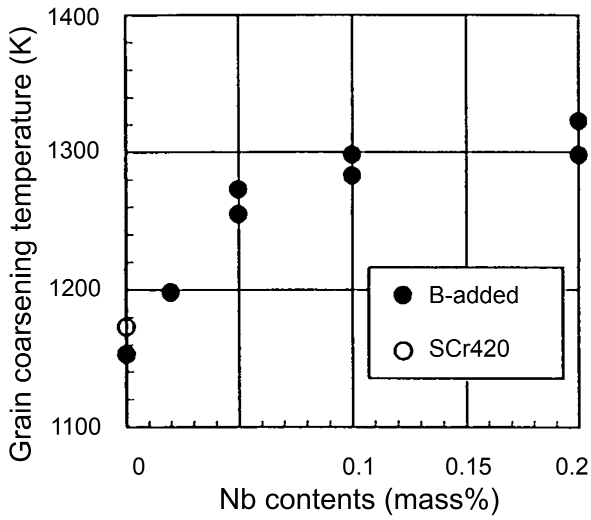


Fig. 19 Effect of Nb contents of grain coarsening temperature.[12)]

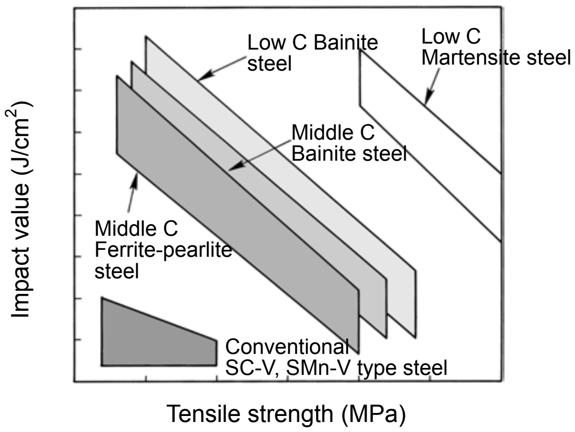


Fig. 20 The relation between tensile strength and impact value among various HTFF Steels.[13)]

9. HEAT TREATMENT FREE FORGING STEEL (HTFF)

Fig 20 shows HTFF steels with various tensile strength which are composed of ferrite-pearlite bainite and low C martensite, however ferrite-pearlite steel is the most popular[13)].

The flow stress of ferrite-pearlite steel σ_B is expressed by Eq(1) in which f_α and f_P are volume fraction of ferrite and pearlite, d_α and L_P are grain diameter of ferrite and lamellar spacing of pearlite respectively. Others are constants.

$$\sigma_B=\sigma_0 + f_\alpha k_1 d_\alpha^{-n} + f_P k_2 L_P^{-n} \quad (1)$$

Flow stress of the whole specimen is governed by the mixing law based on the strength of ferrite and pearlite.

In the case of ferrite-pearlite steel with medium C, the best strengthening method with less deterioration of toughness is to reduce Ac1 transformation temperature as low as possible, because lamellar spacing of pearlite becomes finer and the volume fraction of pearlite becomes larger. In this occasion, Mn and Cr contents are increased compared with conventional ones. For example, the conventional chemistry is 0.45C-0.25Si-0.8Mn, however, the new one is improved as 0.30C-0.25Si-1.5Mn-0.3Cr. The alternation decreases Ac1 point from 730°C to 717°C theoretically, but in practice, it decreases from 650°C to 570°C in continuous air cooling because of that Mn and Cr restrain the diffusive transformation.

10. FREE CUTTING STEEL ELIMINATING LEAD (Pb)

From the environmental view point, new free cutting steel eliminating Pb has been developed along two directions in Japan.

One is the steel containing oxides with lower melting temperature and sulfides, in which Ca, S and Ti are involved. The oxide with lower melting temperature assures the free cutting property at the cutting in high velocity, and the sulfide improves the one at the cutting in low velocity.

The other direction is concerned with the steel having shape-controlled sulfides which contain Zr, Te and Se with S. The shape of sulfides is altered from bar to sphere, resulting in improving elongation, Charpy impact value and the anisotropy of mechanical properties. Fig 21 shows the relation between mechanical property and

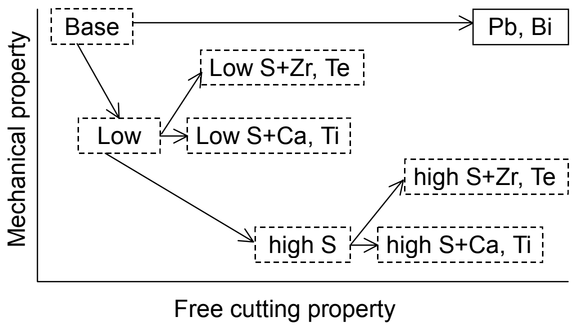


Fig. 21 The relation between free cutting property and mechanical property in terms of chemical composition

free cutting property in terms of chemical composition.

The largest problem is how to compromise mechanical property, especially toughness and fatigue property, with free cutting property.

11. CONCLUSION

Automobiles are always being improved to satisfy the social demand like environmental problems and traffic safety, however, customers' demand such as cost and amenity should also be satisfied at the same time. The compromising is difficult but challengeable, when automotive materials will play more important role in world-wide scale. We have to join the competition for the progress with great ambition.

REFERENCES

1) H. Takechi: Proc. of "IF Steels 2003", ISIJ, p.63 (2003)
2) T. Urabe, T. Fujita, K. Nakajima, F. Kitano and Y. Hosoya: Proc. of "IF Steels 2000", Iron & Steel Society, p.215 (2002)
3) O. Matsumura, Y. Sakuma and H. Takechi: Trans. Iron steel Inst. Japan, Vol.27 p.570 (1987)
4) H. Takechi: Proc. of "Developments in the annealing of sheet steels" TMS, p.3 (1991)
5) S. Hiwatashi, M. Takahashi, T. Katayama and M. Usuda: Journal of JSTP, Vol.35 No.404 p.1109 (1994)
6) H. Takechi: Proc. of "HSLA Steels' 2000" The Chinese Society for Metals, p.113 (2000)
7) W. Bleck, K. Hulka and K. Papamantellos: San Sebastian, Trans Tech. Publications, Switzerland, p.327 (1988)
8) K. Shibata, K. Kunishige and M. Hatano: Ferrum ISIJ. Vol.7 No.4 p.18 (2002)
9) M. Yamada, Y. Tokunaga and K. Ito: Seitetsu Kenkyu, No.322 p.90 (1986)
10) Y. Morimoto, E. McDevitt and M. Meshii: ISIJ Int., Vol.37 No.9 p.906 (1997)
11) Y. Oki: Ferrum ISIJ; Vol.8 No.9 p.13 (2003)
12) Y. Kurebayashi and S. Nakamura: CAMP. ISIJ: Vol.12 p.471 (1999)
13) T. Ochi, H. Takada, M. Kubota, H. Kanizawa and K. Naito: Shinnittetsu Giho, No.370 March p.11 (1999)