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RECENT PROGRESS IN THE TECHNOLOGY FOR IF STEELS

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Abstract

The controlling factor of surface defects occurring in continuous casting is described in terms of the Ti and Nb effect. IF steel produced by thin slab casting process is introduced. IF treated steel produced from scrap is suggested as an alternative to producing a new kind of steel sheet. The effects of Nb in the batch annealing process and galvannealing process are described. A new IF steel coated with Sn-Zn eliminating Pb was developed for gasoline tank of cars.

Surface Defects of IF Steel Sheet Originated in Continuous Slab Casting

The types and features of the defect originated in continuous casting of IF steel are divided into four groups: sliver, pin hole, blow hole and separation as shown in Table I.

Table I. Types and features of the defects affecting the sound quality of steel sheet

Defect		Appearance	Original defect in slab
Surface Defects	Sliver	Longer and linear defect along the length of coil. Normally it is opened, and there exist inclusions at the opening ends.	Inclusions located at the surface or under the surface within about 3mm. They are divided into alumina group and powder group.
	Pin hole	Shorter and linear defect along the length of coil. Normally it occurs widely spreading on the coil surface. Bitten scale is sometimes observed.	A bubble-accompanied inclusion, which was caught by the surface layer, is rolled, and it is opened at the surface.
	Blow hole	Wider and linear defect along the length of coil. It is inflated at the surface layer, and it can be visual in spite of being short in size.	A bubble accompanied inclusions which was caught under the L surface within about 10-30mm is rolled, and is inflated to the surface. It appears at the edge of width.
	Separation	Linear but sometimes slant to the length of coil. The size of defects depends on the kind of original crack.	Crack or rubbed defect on slab surface is remained in original state or after opening the mouth.

The reason why IF steel containing Ti has more surface or inner defects than those of Nb containing IF steel and Al killed steel can be considered as follows.

(1) IF steel tends to cause nozzle closing, because carbon content is very low introducing more oxygen, and when Ti is included, Ti reacts with the refractory of the nozzle and changes the quality. Al_2O_3 tends to stick to the nozzle.

(2) Origin of sliver tends to be formed at the center of mold as shown in Figure 1-(1), because stagnation of molten steel catches Al_2O_3 particles.
In the case of Ti-IF, Ti tends to reduce SiO_2 in the molten powder and much TiO_2 is formed. Such kind of the alternation of composition makes the viscosity of molten powder less and surface tension of the meniscus is also decreased as shown in Figure 1-(2) and Figure 2. Then Al_2O_3 particle in powder can be caught in molten steel so easily followed by being the origin of sliver. On the contrary, Nb-IF never gives such a harmful effect to the sheet surface. When argon bubbling is injected from an immersion nozzle too much, disturbance of the meniscus accelerates the catching of Al_2O_3 particle in molten steel as shown in Figure 1-(3).

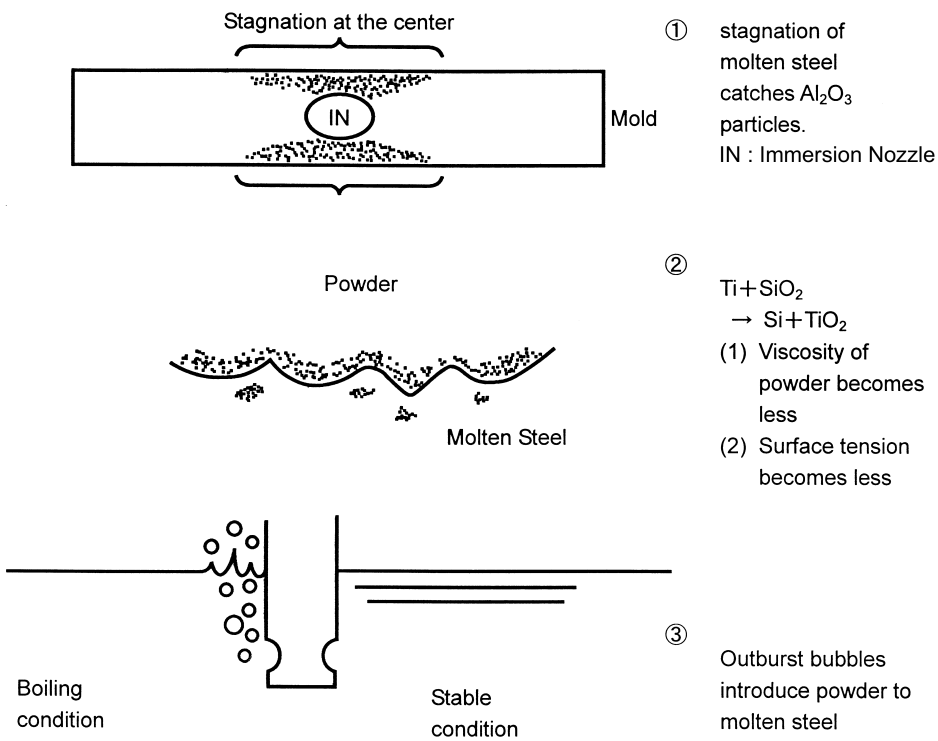
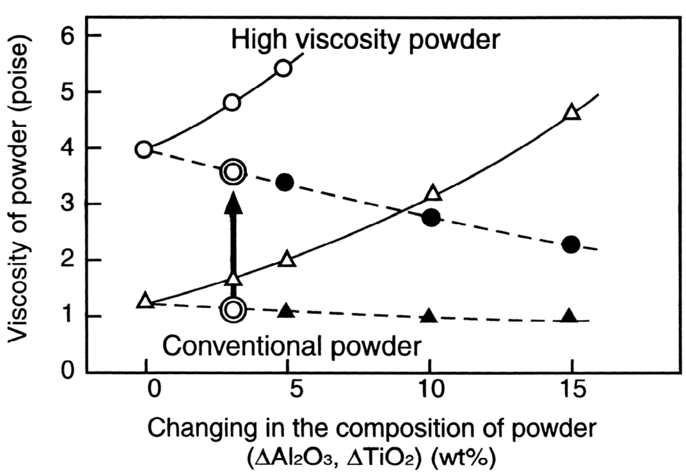


Figure 1. Origin of slivers in slab casting.



Powder		
A	○	Al_2O_3
	●	TiO_2
B	△	Al_2O_3
	▲	TiO_2

Figure 2. The effect of powder composition on the viscosity of molten powder.

(3) In the case of IF steel, argon bubbles and non-metallic inclusion tend to be caught in the surface layer of slab easily as shown in Figure 3. As IF steel belongs to ultra low carbon steel family, the solidifying temperature is high and the difference in the temperature between liquidus and solidus line is small. Then the area in which liquid and solid phase co-exist is very thin, and the solidifying rate is fast. So floating bubbles and non-metallic inclusions tend to be trapped by the solidifying shell easily. In most argon bubbles, fine particles of Al_2O_3 are trapped as shown in Figure 4. Suitable argon bubbling should be maintained in accordance with Figure 1-(3). Sliver defects by appearance are shown in Table II.

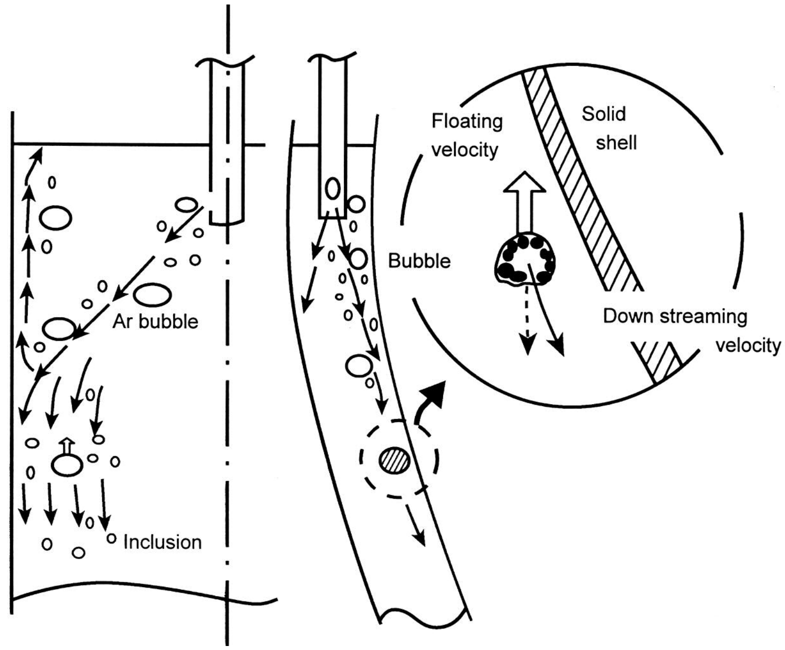


Figure 3. Origin of blow holes in slab casting.

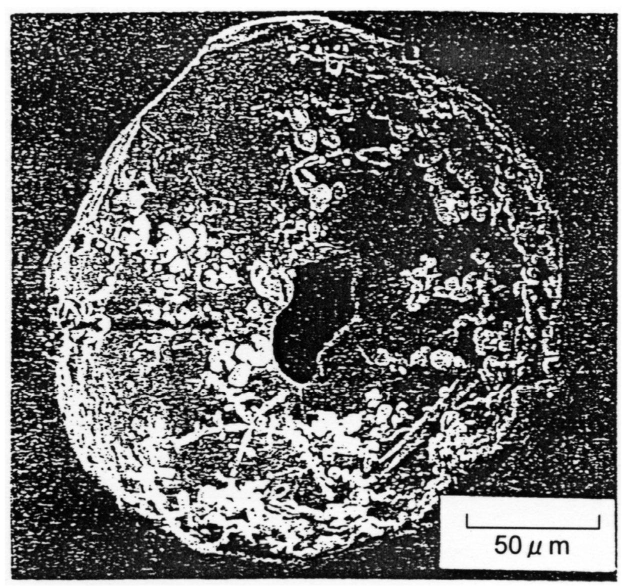


Figure 4. A bubble remained in slab contains fine Al_2O_3 particle with various shapes, which size is 10μm at the largest.

Table II. Sliver defects by appearance.

	Sliver	Fine sliver	Printed defect
Location	Concentrated to the central zone in the width of steel sheet. They appear on the both surfaces of a steel sheet, expanded linearly along rolling direction.		
Length (mm) Width (mm)	< 2000 < 5 (Width is almost constant)	< 300 < 2 (Not so long)	< 3000 < 5 (Various length)
Inclusion at the defect	Alumina group Powder group	Alumina group	No inclusions Rolling defect or sliver defect is printed to the opposite surface during batch annealing

IF Steel Produced by Thin Slab Casting and Direct Hot Rolling Process

CSP and MDH processes are actually running in many countries. However, the lack of time for 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 the steel matrix is converted to be interstitial free, for example, the disadvantage could be saved for deep drawability. Five kinds of specimens were cast into thin slabs with a thickness of 50 mm, followed by direct hot rolling, when the thickness was reduced to 5 mm [1]. Their chemical compositions are shown in Table III. 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.

Table III. Chemical composition of steels (mass%) [1].

	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

Mechanical properties were measured after temper rolling with 0.8% reduction is summarized in Table IV. The microstructure of hot rolled steel sheet turns finer when Nb is added as shown in Figure 5 (C, D) and it can be considered that the mechanical properties are improved to the level of DDQ grade produced with Al killed steel and treated by conventional process.

Table IV. Mechanical properties of specimens [1].

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)

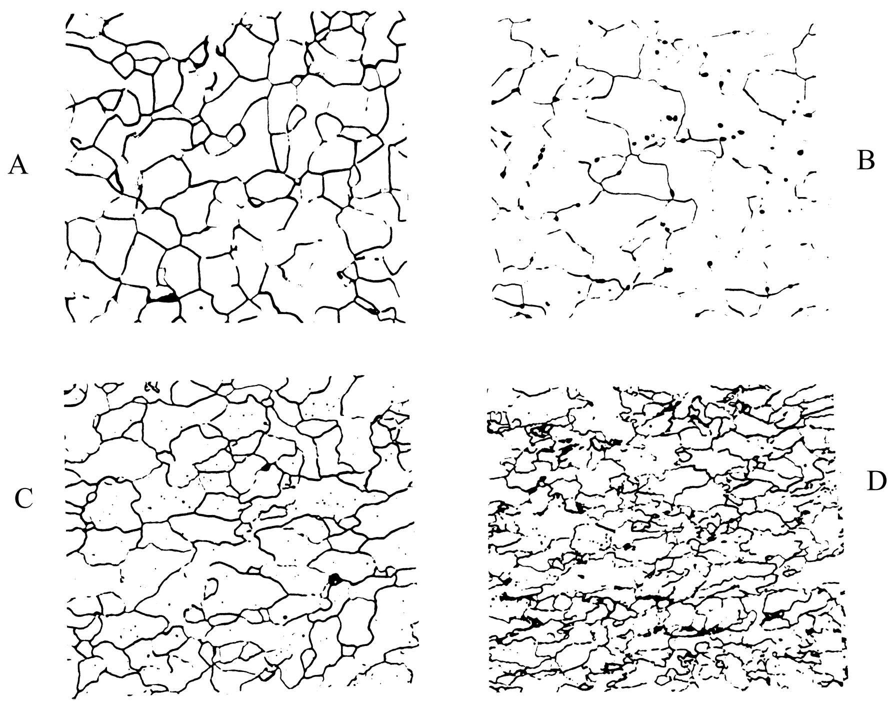
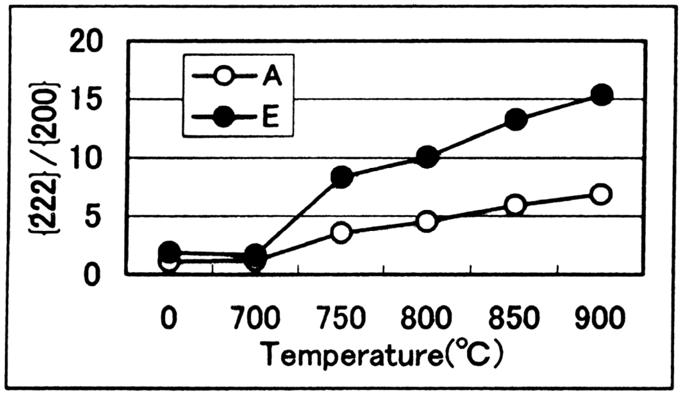


Figure 5. Microstructure of hot rolled steel [1].

{222} oriented grains preferentially grow during recrystallization in the case of Nb added specimen E as shown in Figure 6, which depends on the inhibition of preferred nucleation of {110} recrystallized grains and the consumption of {100} recovered grains. Figure 7 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 specimens by keeping grain boundaries not so clean due to shorter annealing time.



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

Figure 6. Change in textures of specimen A and E during annealing [1].

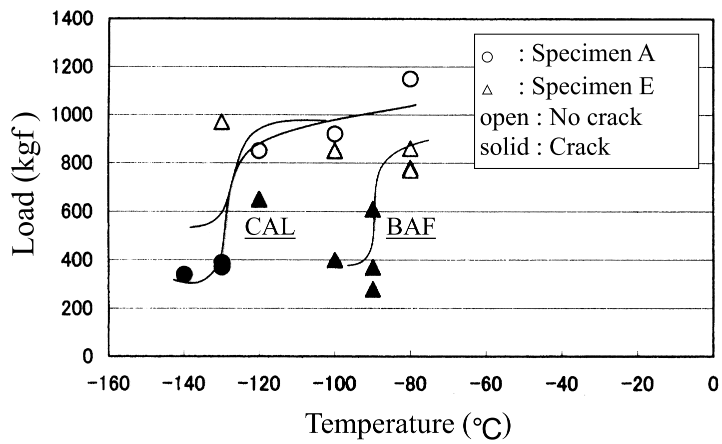


Figure 7. The relation between load and cracking, A and E are specimen No., CAL and BAF are continuous annealing and batch annealing respectively [1].

Steel Sheets Produced With Town Scrap

The accumulation of scrap in Japan exceeds 800 million tons now, and it is still growing. It is very profitable as the resource for steel sheets, if the property could be improved by applying IF technology. Town scrap contains much Sn, Cu, Ni and Cr, which remain in the molten steel as shown in Figure 8. These elements are harmful for formability of steel sheets in general. Yamada tried to check the effect of these impurity elements added to IF steel on the mechanical properties. [2]. Carbon and Ti contents were 0.0012 - 0.0030% and 0.053 ~ 0.057% respectively. Figure 9 shows the relation between the impurity content and mechanical properties. It is obvious that Sn is the most harmful, but others are not so critical. It could be concluded that town scrap is useful for steel sheets in deep drawing grade (DDQ), when Sn content is controlled to be less than 0.03% and the base metal is IF steel. According to NSC's data in Figure 10, Cu is very effective to improve the anti-corrosion property of steel sheets under in conjunction with P. Steel sheets produced with town scrap and IF technology containing a controlled quantity of Cu and P (more than 0.03%) and could be a candidate for new DDQ grade with good anti-corrosion properties.. Recently Shibata [3] pointed out that Sn and Cu cooperate to accelerate cracking during hot rolling, however, slab reheating temperature higher than 1200°C tends to avoid the cracking as shown in Figure 11.

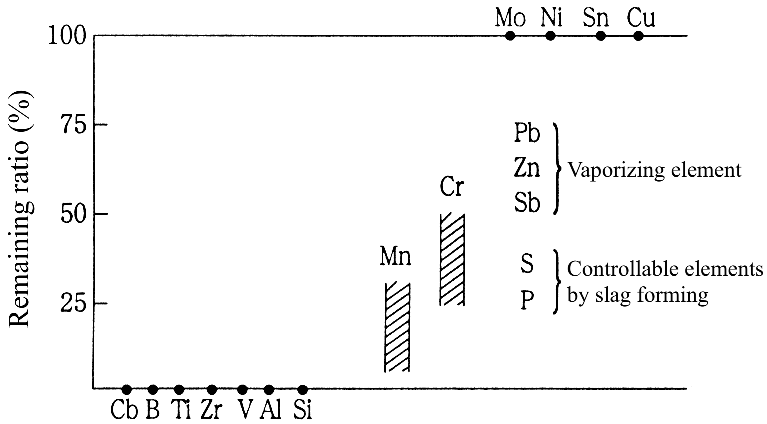


Figure 8. Recyclability of impurity elements in scrap.

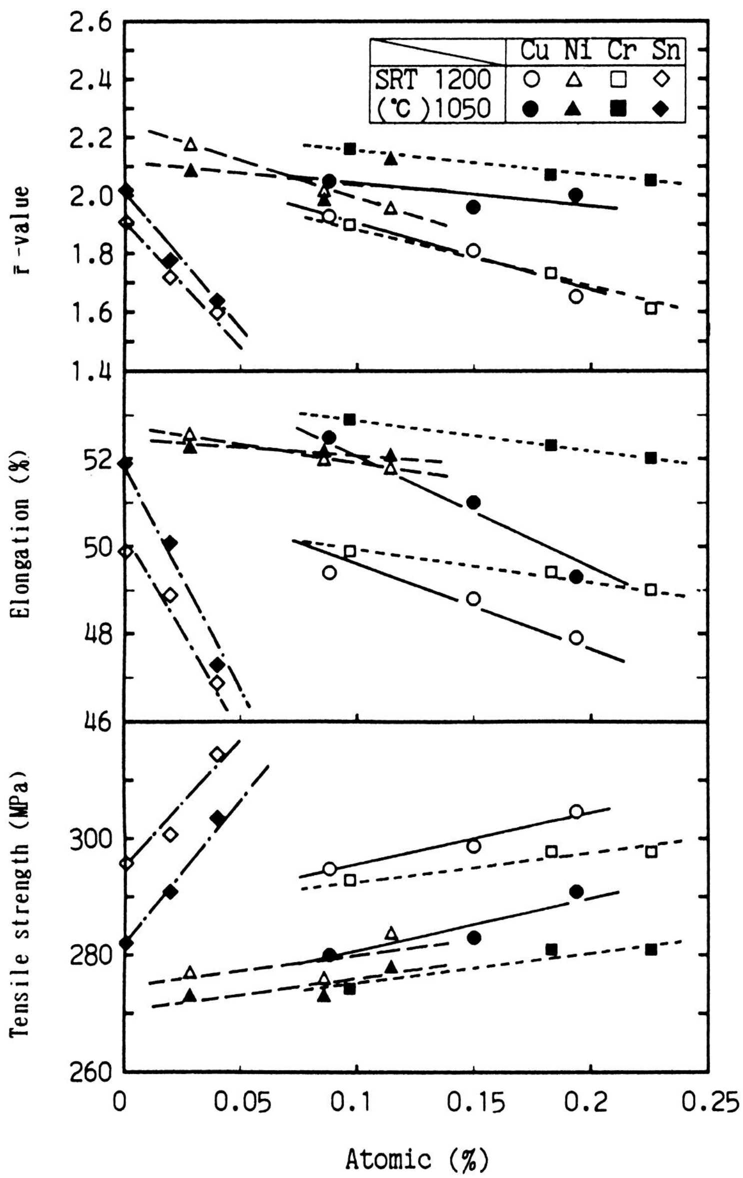


Figure 9. Relationships between atomic percent and mechanical properties of Cu, Ni, Cr and Sn-containing titanium-bearing extralow-carbon steel sheets [2].

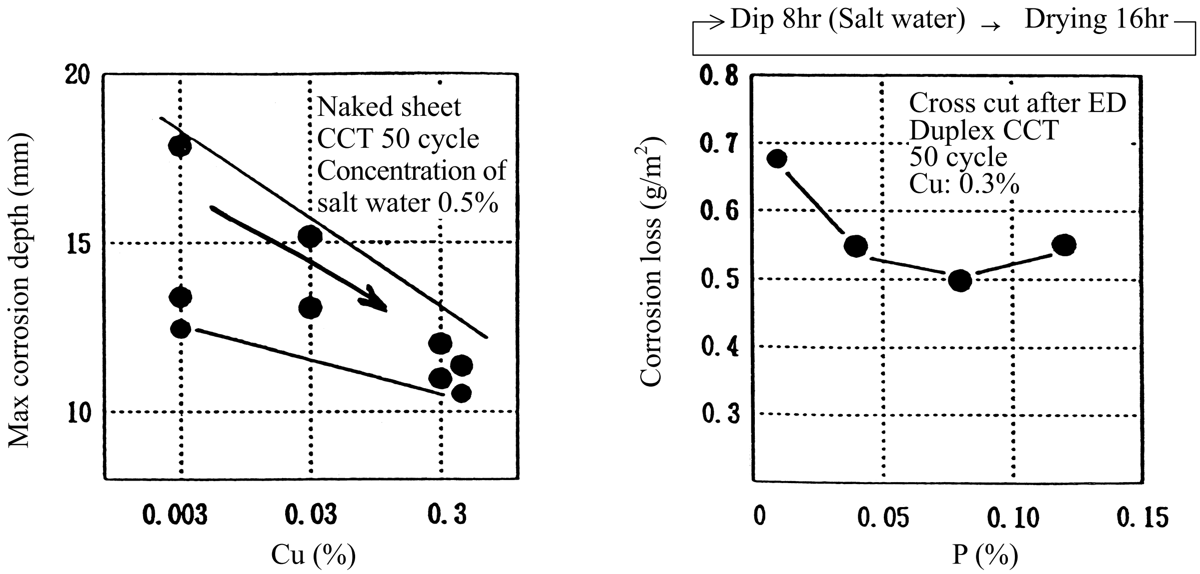


Figure 10. The effect of Cu and P on the corrosion resistant property.

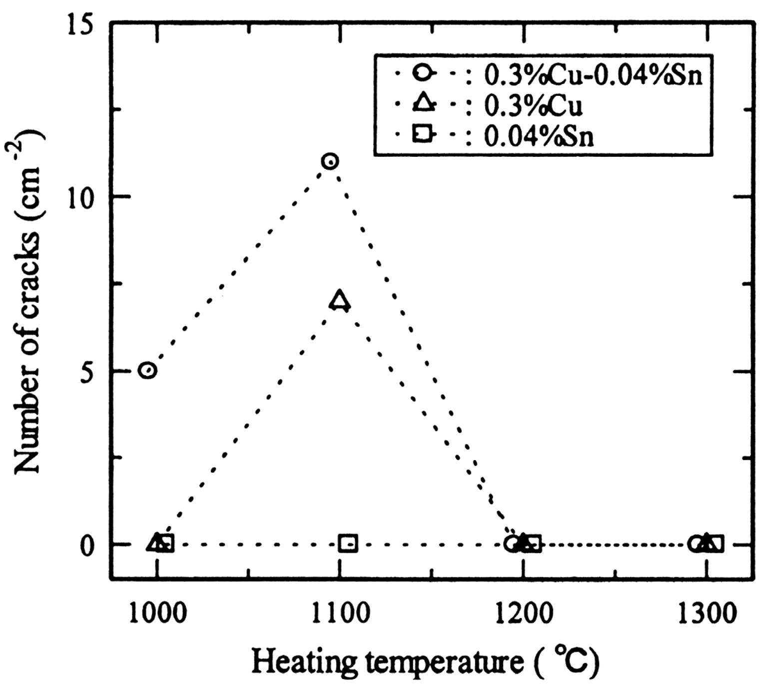


Figure 11. Effect of heating temperature on the surface cracking caused by Cu and Sn [3].

IF Steel Sheets Produced by Batch Annealing Process

Although it is well known that the formability of IF steel sheets is improved as annealing temperature is raised, the annealing temperature in batch annealing is impossible to be raised beyond the critical temperature due to thermal sticking of the sheet. However, IF steel is actually produced by batch annealing in many steel plants throughout the world. It is necessary to pay attention to the processing condition in this case. Figure 12 and Figure 13 show the effects of coiling temperature and heating rate during annealing on $\overline{r}$ value respectively [4]. It is obvious that the $\overline{r}$ value of IF steel is almost constant at the both processing conditions in contrast to other steel grades, suggesting that the texture formation of IF steel is not affected by the precipitation at earlier stages of recrystallization, but affected by interstitial-free matrix and the inhibition during grain growth. Akamatsu [5] studied the favorable processing condition for Nb containing IF steel annealed by batch annealing process. Figure 14 shows the most favorite content of Nb for $\overline{r}$ value is located at Nb/C = 11, and Figure 15 shows that fine precipitates in annealing should not be permitted because they inhibit the grain growth after recrystallization. As the annealing temperature cannot be raised in batch annealing process, grain refining in hot rolled steel sheet and large reduction in cold rolling should be applied in allowable limit.

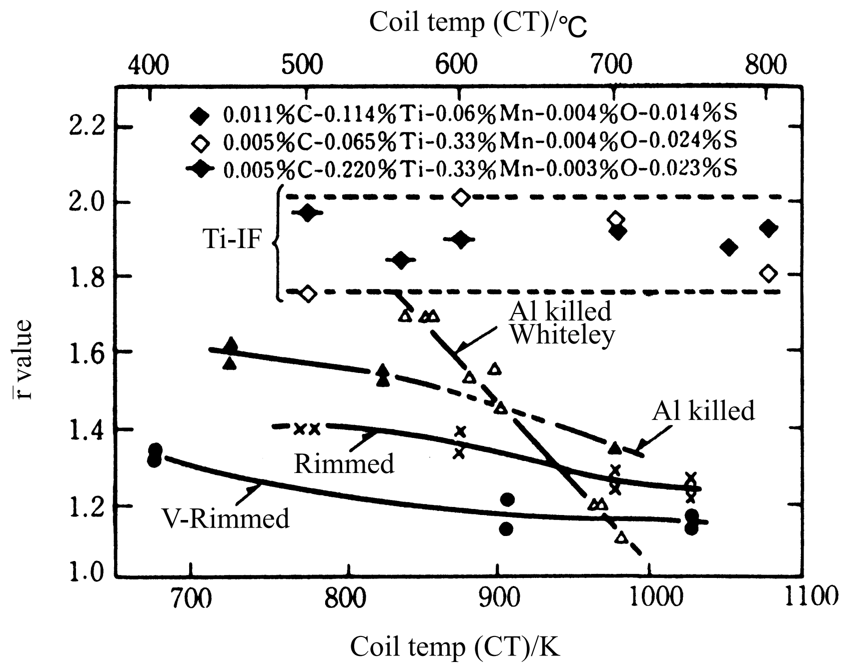


Figure 12. The effect of coiling temperature on $\overline{r}$ value of steel sheet annealed at 700°C for 5 hrs [4].

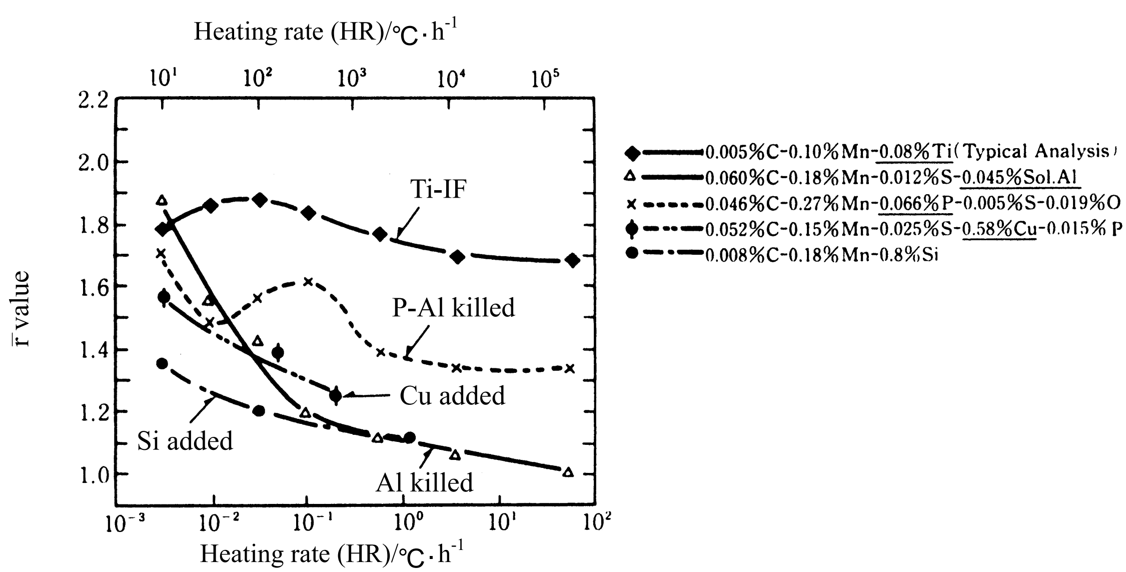


Figure 13. The effect of heating rate on $\overline{r}$ value of steel sheet annealed at 700°C for 5 hrs [4].

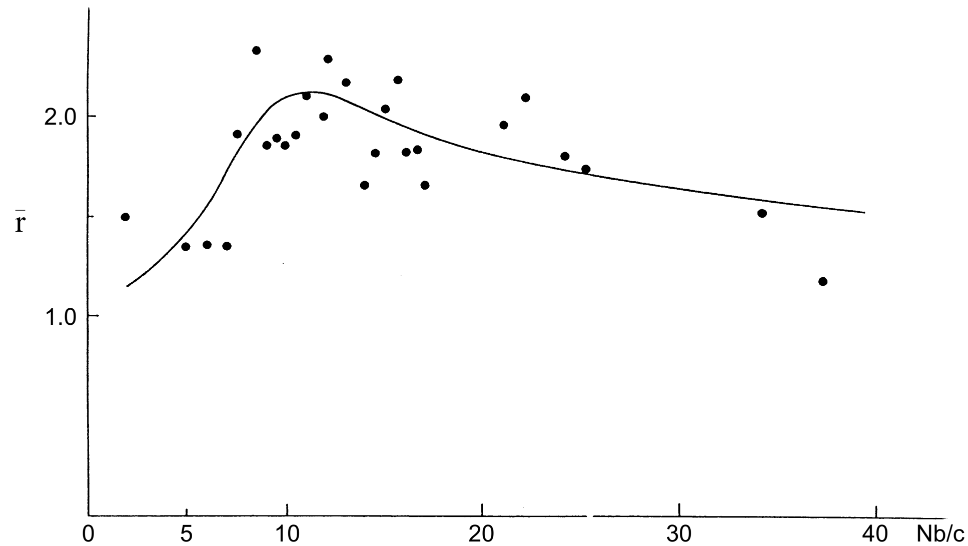


Figure 14. Relation between $\bar{r}$ value and Nb/C of cold rolled-annealed sheets [5].

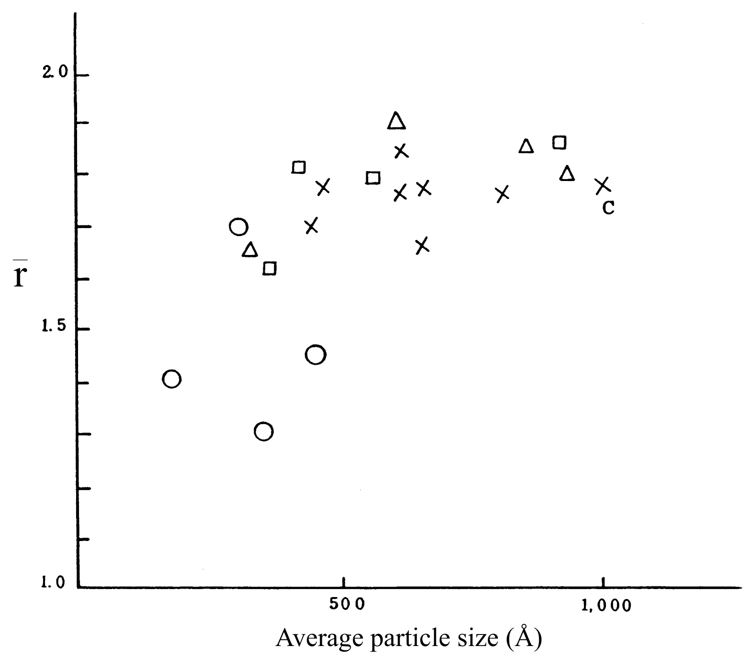
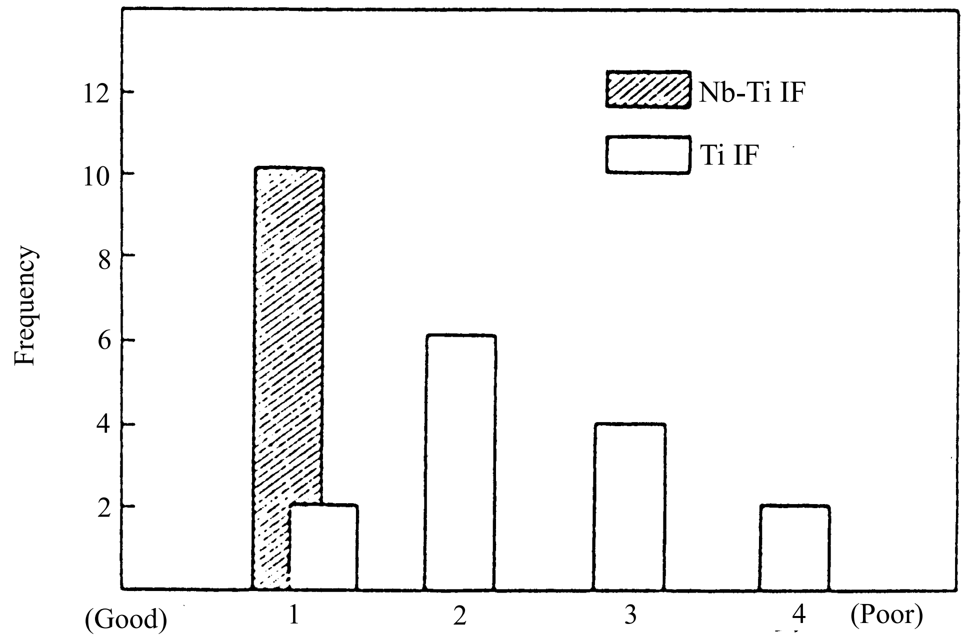


Figure 15. Relation between $\bar{r}$ and average particle size of cold rolled-annealed sheets [5].

Adhesion Properties of Zinc Coated Layer on Galvannealed IF Steel Sheet

Galvannealed Nb-Ti IF has better adhesive properties of coated zinc than Ti IF as shown in Figure 16 [6]. In general, Al in zinc bath concentrates at the interface between molten zinc and the steel matrix, forms the Fe-Al-Zn intermetallic phase which inhibits the formation of Fe-Zn alloying layer. Meshii [7] 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 the alloying layer between Ti IF and Nb-Ti IF in Figure 17 [6].



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

Figure 16. The effect of chemical composition on the adhesion of zinc coated layer [6].

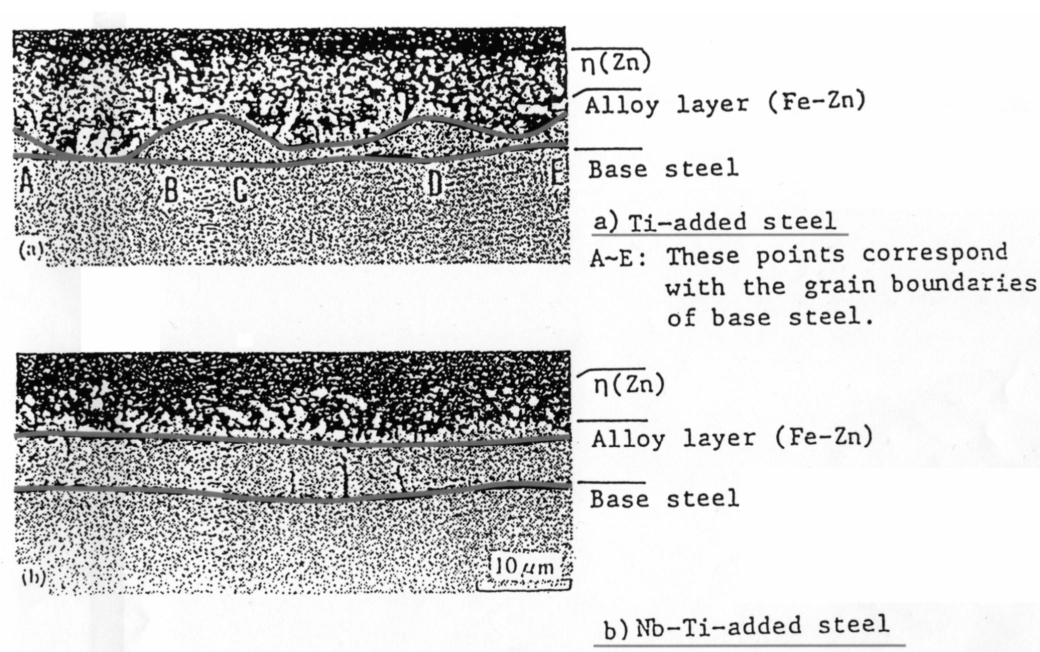


Figure 17. Alloy layer in the middle of growth [6].

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 tanks have been changed to more complicated shapes because the space in which the tank should be installed has been narrowed and more complicated due to because the need for weight saving and downsizing of cars. Gasoline tanks are generally coated with terne metal, which tends to deteriorate the formability of steel sheets. In that occasion, IF steel is very useful to be formed to the complicated shape when metallic coatings are applied.

Recently Nippon Steel Corp. developed a new IF based steel sheet for gasoline tanks, which is coated with Sn-Zn metals eliminating Pb in terne sheet from an environmental viewpoint. This one is more superior in formability and anti-corrosion than the conventional one as shown in Figure 18 and Figure 19 respectively. IF steel is known to cause a problem called cold working embrittlement, which is a kind of grain boundary fracture. But niobium containing IF steel with a 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 V. B, Nb and uncombined C atoms would stabilize grain boundary followed by decreasing the transition temperature.

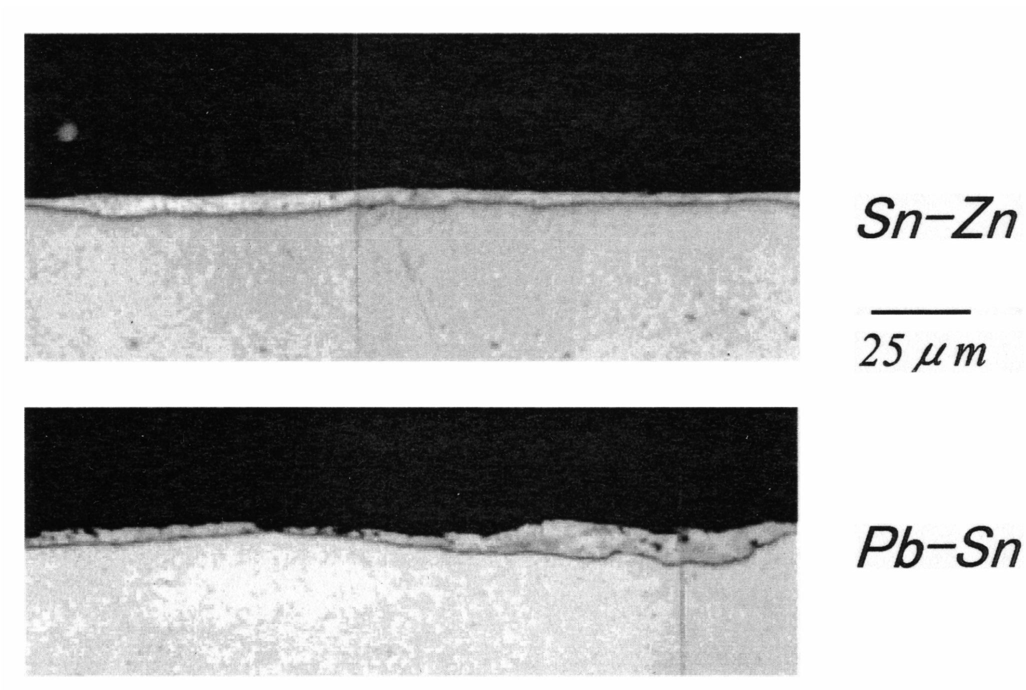
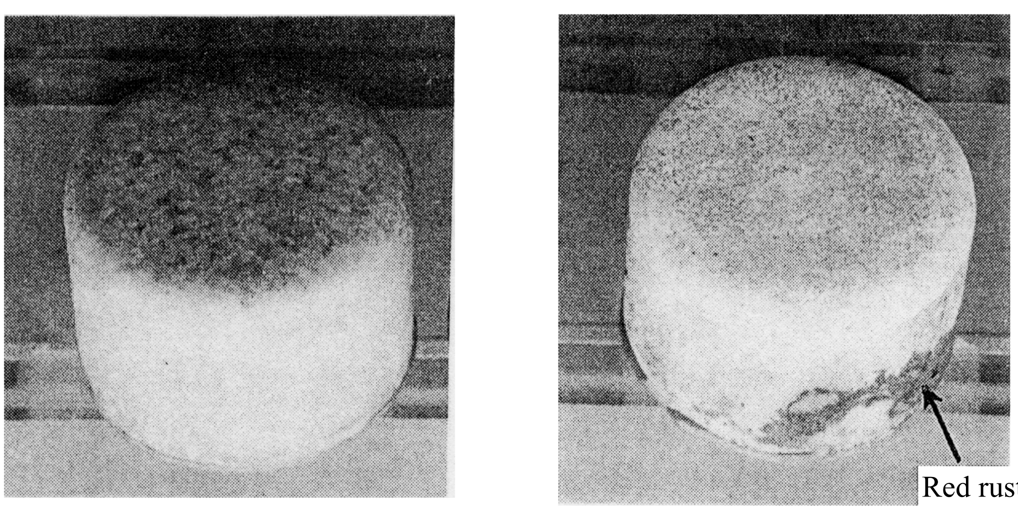


Figure 18. Damage of coated layer after draw-bead test.



Sn - 9%Zn   Terne sheet

Figure 19. Anti-corrosion property of IF based Sn-Zn coated steel sheet.

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

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

Note : C=22～30ppm

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

A Suggestion to the Formation Mechanism of {111} Texture in Iron

According to the analysis by Prof. H. Abe, Osawa [8] showed the harmful effect of Mn-C dipole on {111} texture formation as shown in Figure 20.

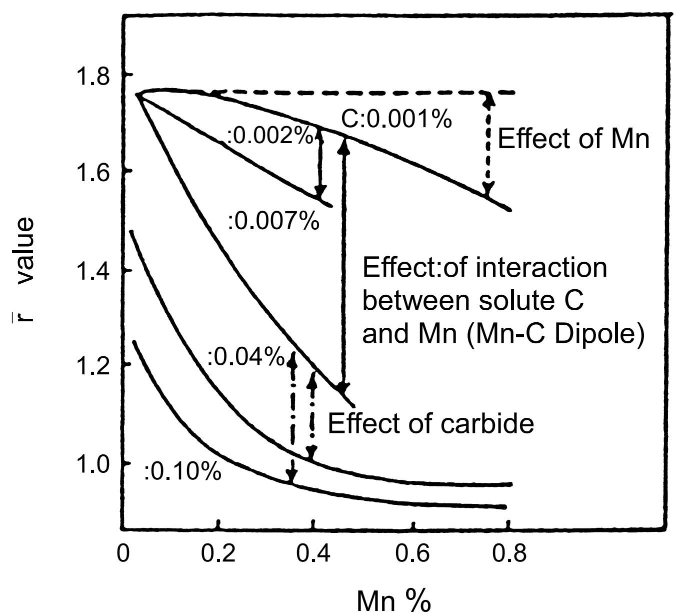


Figure 20. Schematic illustration of the effects of various metallurgical factors on the decrease in $\bar{r}$-value [8].

They suggested that very fine Mn-C dipole in atomic order inhibits the growth of nucleated {111} texture at very early stage of recrystallization. With no carbon in solution, the Mn-C dipole never forms which could be the reason why IF steel can have a higher concentration of {111} texture during recrystallization. Another phenomenon has been obtained in our experience, when producing deep drawable steel sheet by the both of batch and continuous annealing. As it is well known, there is an order of alloying elements, which indicates the tendency for making graphite in iron. According to experience, the order for graphitization appears to have a relation with the formation of {111} texture in iron as shown in the following.

[Strong ability to form graphite] ←→ [Weak ability to form graphite]

Si	Al	Ni	P	Cu	Co	W	Mo	Mn	V	Cr	S
No harmful or contributive to obtain higher $\overline{r}$ value								Harmful to obtain higher $\overline{r}$ value			

It is not yet obvious why an interstitial atom like C is harmful to the formation of {111} texture during recrystallization in iron. That could be an interesting problem to be investigated.

7. CONCLUSION

It is commonly believed that the demand for IF steel and its technology is vanishing because the industry focuses on stronger material such as HSS or super HSS. However, very soft and very clean IF steel approaching pure iron could reveal many products and information in regard to the anti-corrosive, electro-magnetic and energy absorbing properties as well as composite materials, regeneration of wasted and impure materials like scrap and so further. It is also useful to know the basic property of pure iron more deeply. Thus the study on IF steel should be continued in the future.

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