Sheet Steel Products and their Application Technology for Automotive Uses

by
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Synopsis

Changes in hot, cold and coated sheet steel products, and current standard production by SMI for automotive uses are presented and discussed. For application of these steels to automobile production, press-forming, joining/welding, anti-corrosion, anti-fatigue and crash worthiness evaluation technologies developed by SMI are described.

1. Introduction

Since more than half of sheet steel products of SMI is shipped to automotive related industries, SMI's production and research targets have been focused on automotive uses and have changed corresponding with their needs and production system[1),2)]. While then various difficulties for usage of new sheet products have been overcome by cooperate research activities with customers. This paper describes the outline of SMI sheet steel products and the application technologies developed for sheet steels[3)].

2. Hot and Cold Rolled Sheet Steels

2.1 Changes of Materials

The SMI production of sheet steel started in Wakayama steel works in 1962 and in Kashima steel works in 1969. At that time, the Rimmed steel was a major material for sheet steels. The aluminum core-killed steel was used only for deep-drawing parts, since this steel exhibited sound surface as rimmed steel and a high r-value and non-ageing property as the Al-killed steel, but yield was poor. Owing to the development of continuous-casting technology, the Al full-killed steel came to be manufactured in a large quantity with good yield and good properties. This and following changes of materials in Japan are shown in **Fig. 1**. However, by the lack of the interstitial elements and thus the non-ageing property of the Al-killed steels, the "Dent problems" arose in the exposed panel of automobiles. This provided a trigger for the development of bake-hardenable (BH) steels[4),5)].

On the other hand, the annealing process was switched from batch annealing to continuous annealing, and thus the material changed gradually from low carbon steels to ultra-low carbon steels. As recognized from the figure, the major materials for sheet steels have altered almost every five years. This drastic change was induced by the development of steel making technology which enabled an efficient reduction of carbon content in steels, as shown in **Fig. 2**. At present, the drawing quality steels for exposed panels are produced mainly from ultra-low carbon steels with controlled amount of carbon for bake-hardening property.

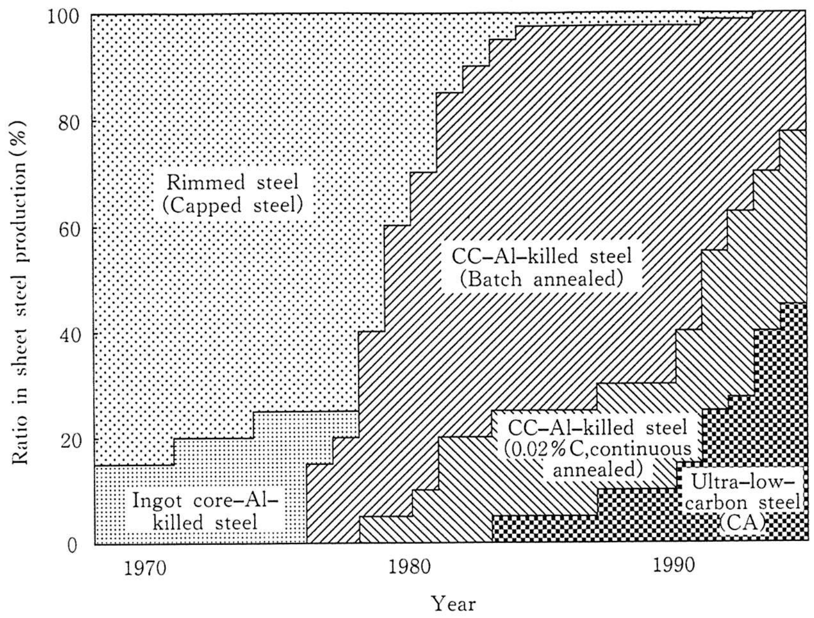


Fig. 1 Changes of steel for cold-rolled sheets

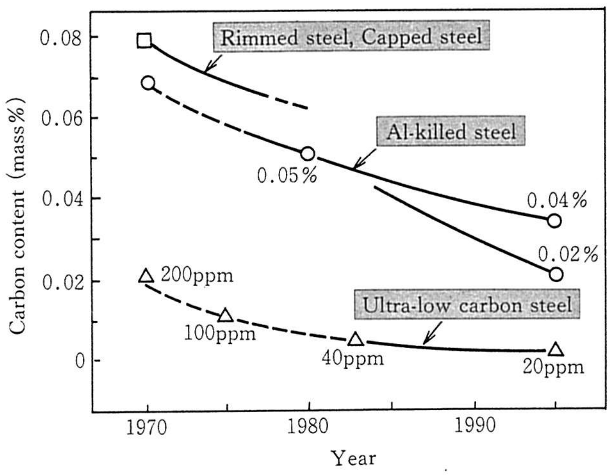


Fig. 2 Decrease of carbon content in cold-rolled sheet steels

2.2 Cold Rolled High Strength Sheet Steels

Table 1 lists up currently producing and developing high strength steel grades of SMI[6]. The grades are compared with JFS (The Japan Iron and Steel Federation Standard) A-series standard for reference. Starting from cold rolled steels, "Commercial type" and "Welding type (Sumitomo standard SCA***W)" are appropriate for simple forming uses. In the latter type, Nb and Ti are added especially to achieve the high yield strength. "Deep drawing type (R)", added with substitutional elements such as P, is for severe forming. "Extra deep drawing type (X)" exhibits higher formability with a higher r-value and n-value and is produced by ultra-low carbon steels. The hardening elements are Mn and P. "Bake-hardenable type(RBH)", which exhibits anti-denting after paint-baking treatment by the yield strength increase of 40 MPa, is manufactured also from ultra-low carbon steel through severe control of dissolved carbon of about 10 ppm[7,8]. The tensile strength of 300 and 340 MPa class is currently used for the exposed panels. "Low yield ratio type (D)" exhibits the high n-value by the existence of the martensite or bainite with a so-called dual-phase microstructure. It shows smaller spring back than commercial steels after stamping. "High ductility type (S)" contains retained austenite phase of 5-20% and has a large ductility because the austenite transforms to martensite during deformation. Moreover, it was recently disclosed that the steel exhibits 10 to 15% larger energy absorption than the same strength steels at a high speed impact collapse test[9,10].

"Hot dip galvanized steels (Sumitomo standard ACA***)" exhibits the similar properties as cold-rolled steels. However the content of Si in steel is limited for good adherence of the zinc coating.

Table 1 High strength sheet steel grades produced by SMI

Name of steels	SMI standard	JFS A for reference	Typical alloying	Minimum tensile strength (MPa)											
				340	370	390	440	490	540	590	690	780	980	1 180	1 380
Hot-rolled steel															
Commercial-1	SHA***	JSH***J, W	C, Mn		◎*	◎*	◎*	○*	○*						
Commercial-2	SHA***B		C, Mn					◎	◎	◎					
Welding	SHA***W	JSH***R	Nb, Ti				○*	◎*	◎*	◎*	○	○*			
Low-yield ratio	SHA***D	JSH***Y	C, Mn						○*	○*		◎*			
High hole-expanding	SHA***H		C, Si, Mn				◎	◎	◎	○	○	○			
High ductility	SHA***S		C, Si, Mn							○	○	○			
Corrosion resistance	SHA***CR		Cu, P		○	○	○	◎	◎	◎		△			
H-R, hot-dip galvanized															
Commercial	AHA***	JAH***W	C, Mn		◎*	◎*	◎*								
Welding	AHA***W	JAH***R	C, Mn				◎*	○	○	○					
High hole-expanding	AHAF***H		C, Si, Mn				○	◎	○	△					
Cold-rolled steel															
Commercial	SCA***	JSC***W	C, Mn	◎*	◎*	◎*	◎*								
Welding	SCA***W	JSC***R	Nb, Ti			◎	◎*	◎	◎	◎*					
Deep drawing	SCA***R	JSC***P	C, Mn, P	◎*	◎*	◎*	◎*								
Extra deep drawing	SCA***X	(JSC***P)	Mn, Nb, Ti	○	○	○	○								
Bake-hardenable	RBH***	JSC***H	C, Mn	◎*	△	△									
Low-yield ratio	SCAF***D	JSC***Y	C, Mn							○*		◎*	◎*	◎*	△
High ductility	SCAF***S		C, Mn							○		○			
Corrosion resistance	SCAF***C		Cu, P	◎											
C-R, hot-dip galvanized															
Commercial	ACA***	JAC***W	C, Mn	◎*	◎*	◎*	◎*								
Welding	ACA***W	JAC***R	Nb, Ti		○	◎	◎*	○	○	○					
Extra deep drawing	ACAF***X	JAC***P	Mn, Nb, Ti	◎*	○	◎*	◎*								
Bake-hardenable	ACRBH***	JAC***H	C, Mn	◎*	△	△									
Low-yield ratio	ACAF***D	JAC***Y	C, Mn							○		△	△	△	

* : JFS (The Japan Iron and Steel Federation Standard)
◎ : Current commercial production ○ : Developed grade △ : Developing grade (Under mill trials)

2.3 Hot Rolled High Strength Sheet Steels

In hot rolled steels, "Commercial type 1" is for simple press-forming uses. "Commercial type 2 (Sumitomo standard SHA***B)" and "Welding type (W)" are for rims and discs of road wheels uses[6]. For their anti-fatigue properties and anti-strength-drop at the heat affected zone of welding, Nb and Ti are added besides C and Mn alloying. "High hole expanding type (H)" is the steel whose hole-expansion limit is improved by about 50 % by diminishing the cracks occurrence usually generated by the blanking process. This is achieved by decreasing the hardness differences between ferrite and bainite phases by adding certain amount of Si. The steel is valid for under body members and light weight wheel discs[11,12]. "Corrosion resistance type(CR)" showing better corrosion resistance than conventional steels by a factor of two but inferior to coated steels is used mostly for cost saving[6].

Various types of "Hot dip galvanizing steels (Sumitomo standard AHA***)" are also produced as cold rolled steel bases.

3. Coated Sheet Steels

The application of coated steels to white body panels was started with "One-side zinc-rich painted steel (ZINCROMETAL)" developed in USA and, in some case, "One-side coated galvannealed steel (45g/m^2)". Afterwards, in order to meet Canadian-code and more severe requirement of 10 years of anti-perforation and 5 years of anti-cosmetic corrosion, and also for better stampability and weldability of steels, various types of coated steels were tested and developed, as shown in **Fig. 3**.

In 1980's, electroplated steel sheet (SECA) was used because of the easiness for a suitable surface quality and formability. "Zn-Ni alloy thin plated steels (SZCA)"[13] was a representative of the electroplated steel because of its superior corrosion resistance characteristics. Afterwards it was progressed to "Thin organic composite film double coated steel"[14] and, at present, it was modified to a thinner Zn-Ni electroplated composite steel "TOUGH COAT 4 (TC-4)"[15] having a better corrosion resistance and weldability. As the other high corrosion

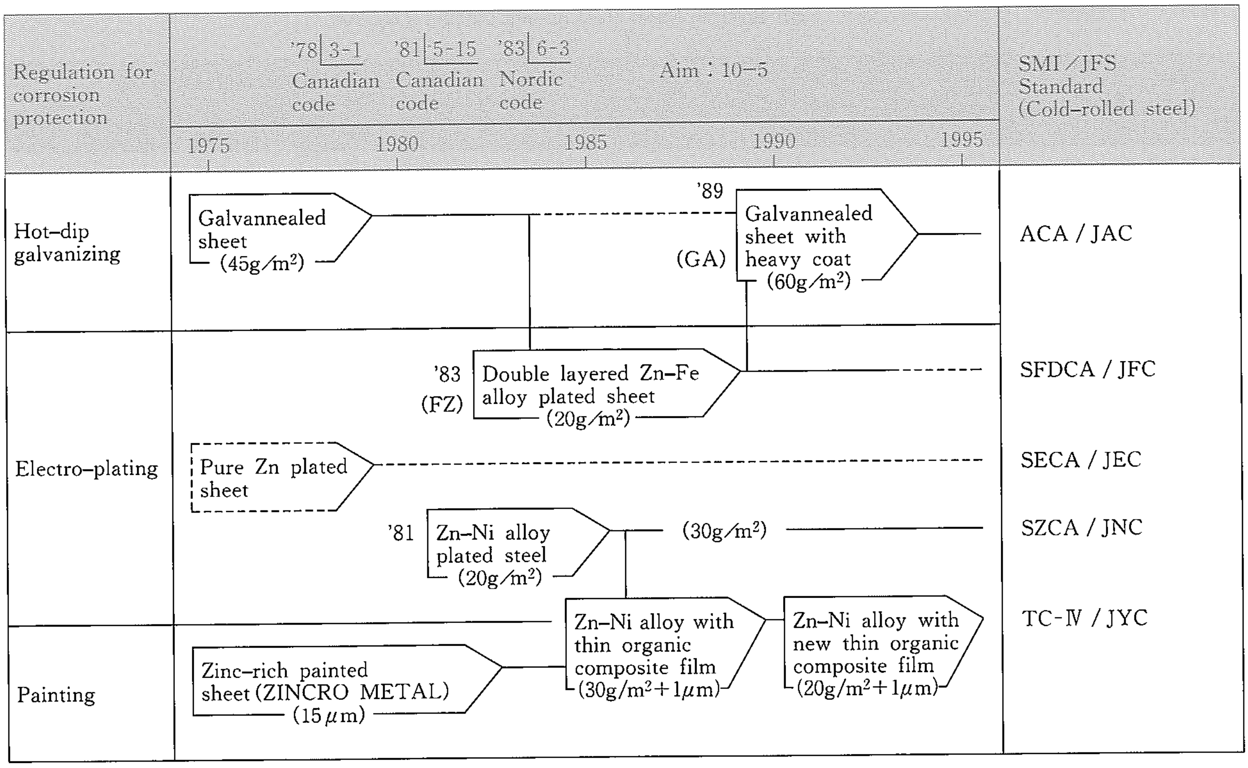


Fig. 3 Trends of surface treated steel sheets for auto-body panels

resistance electroplated steel sheet, "Double layered Zn-Fe alloy plated steel (SFDCA)"[16] was used. Its surface Fe content was increased, for the better formability, weldability and the ED paintability.

Owing to the advancement of the steel making technology for ultra-low carbon steels, and also to the operating technology for continuous hot-dip galvanizing line, "Thick coated galvannealed sheet steel (ACA)" was then applied to the exposed panels. In some cases, thin Fe rich Fe-Zn alloy plating was performed to the surface for the improvement of formability, weldability and surface paintability. Besides the above situation in Japan, very thick pure zinc electroplated steel sheet or non-alloyed galvanized sheet steels are used for the exposed panels in European countries.

The anti-perforation property and the anti-cosmetic corrosion property of typical corrosion resistance steels are compared in **Fig. 4**. A pure zinc based coating is preferable for edge and stone chipped part corrosion after painting, because of the sacrificing effect of zinc. On the other hand, alloy coating is preferable in the aspect of preventing perforation corrosion of incomplete ED painted area. Due to the difference in corrosion control design and in body panel manufacturing procedure

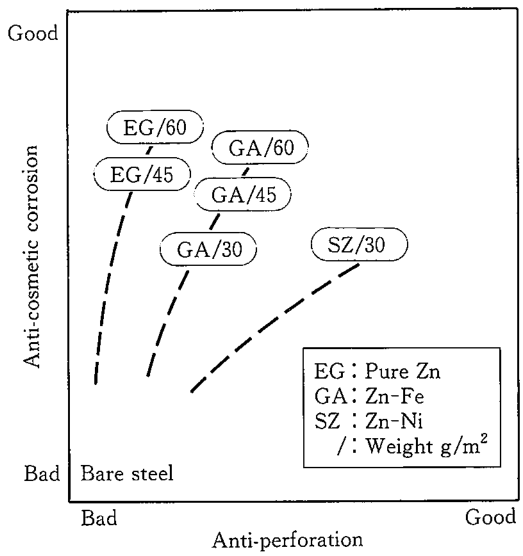


Fig. 4 Comparison of anti-corrosion properties for coated sheet steels

among the automotive makers, the variety of coated steels are being used. A steel satisfying both anti-perforation and anti-cosmetic corrosion properties with a thin coat is desirable.

As for the exhaust pipe systems and for heat proof parts, 55% Al-Zn coated steels(ALUZINC)[6] is being to be used instead of Al-plated steels and stainless steels. In addition, the application of amorphous Al-Mn coated steel steels[17] and Zn-Ni coated

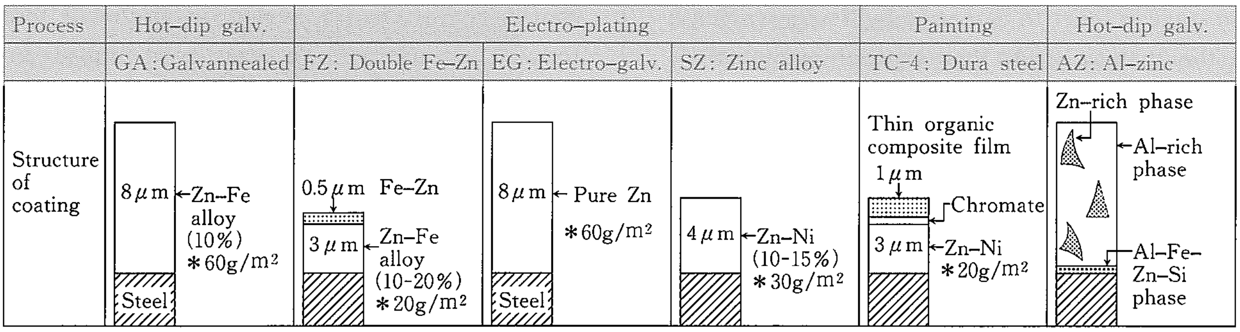


Fig. 5 Typical coating film composition of coated sheet steels for auto-body panels

steel with thick chromate film, SZ-GTX[6], are anticipated for new materials of fuel tanks. **Figure 5** shows the film structure and composition of typical coated sheet steels for reference.

4. High Carbon Sheet Steels

Various grades of high carbon steels are used for transmission parts, such as gears, bearing retainers and chains and also for seat belt metals. A six high cold rolling mill and 100% hydrogen annealing furnaces in Wakayama steel works are being used effectively for manufacturing those products of carbon ranging between 0.2 and 1.0 %(JIS G3311: S, SK, SKS, SCM, SUP, SMn) with high accuracy of thickness and uniform hardness and surface quality. Beside the JIS standard products, anti-delayed fracture steel of 1 600 MPa grade, a very soft(HRC45) but hardenable S35C grade steel and anti-heat-warp steel are produced[18].

5. Application Technology

SMI has been very aggressive in doing a joint research work with automotive makers for the application and development of steel materials. Research equipment and particular topics concerning application and assessment technologies are presented.

5.1 Press Forming

The research of press-forming has been promoted by installing a large-scale 500 ton hydraulic press machine in 1970. Study in wall-breakage and goaling mechanisms and theoretical relation between r-value and texture component were fundamental research fruit in those days. Lubrication films(S-coat) having good removability and dent-resistant BH steels were thus developed materials. For the application of coated steels to body panels, powdering, flaking[6] and lubrication mechanism[6] were eagerly examined and applied to practical performance[19].

Table 2 shows research equipment and application results. Recently, controlled blank holding force system was recognized to be very valid in degrading materials necessary for stamping panels without wrinkle or breakage[6),20]. As shown in **Fig. 6**, for example, the blank holding force is changed from large at the initial stage of stamping to small at the

Table 2 Typical experimental equipment for stamping technology development

Test method	Characteristic application of the test
Actual size stamping test (500 ton hydraulic press machine)	* Stampability evaluation for surface coated steels * Selection of lubrication oil * Controlled blank holding force system technology
Model stamping test (250 and 100 tons HP machines) * 400 mm square flat model panel test * Bead stamping * Hat channel stamping	* Dent-resistance evaluation * Shape-fixability and stiffness assessment * Alloy control for minimum flaking/powdering of GA * Friction evaluation and surface design for coated steels * Spring-back assessment for high strength steels
Die galling test	* TS-coat for high clarity stainless sheet
Modified Bauden test	* Assessment of friction for continuous sliding of flange

end stage in order to escape from breakage criteria of the material. The hat channel examination,

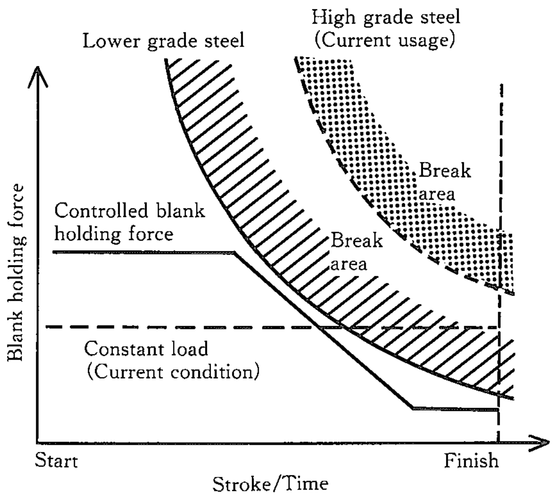


Fig. 6 Application of lower grade material by using controlled blank holding force system

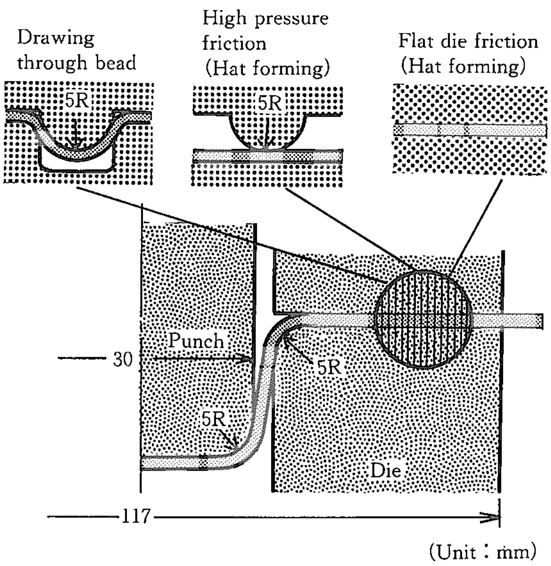


Fig. 7 Evaluation of frictional characteristics through draw beads by hat forming

shown in **Fig. 7**, for evaluating frictional force through various types of draw bead is also very useful for the selection of surface coating. For example, it is used for developing new coating or lubricant substitutable for the galvanneald steel with Fe flash coating.

5.2 Joining

Because of a wide use of the coated and/or the high strength steel steels, the welding condition and an optimum material design which secure the weld portion has been requested and proposed[21]. **Table 3** shows research equipment and examples of the application. Mash-seam welding technology was one of those activities recently presented to customers for the tailored blanking of members and panels, such as center pillars and front side members[22),23)]. In spite of uneven appearance and large area of hardened portion, as shown in **Fig. 8**, the mash-seam welding is becoming very attractive because of its simple and low equipment cost and better strength reliability in contrast with LASER welding. Proposal of optimum gas shielding in arc welding[6),24)] is other face of the research work. The corrosion resistance of under body members is remarkably improved by decreasing the spatter and the blow holes, which is achieved only by decreasing the O_2 composition of the shielding gas in arc welding to 1 to 3 %.

Table 3 Typical experimental equipment for joining technology development

Test method	Characteristic application of the test
Resistance welding * Spot welding * Seam welding * Mash-seam welding * DC-butt welding * Flash-butt welding	* Weldability assessment for coated or alloy steels * Surface design for GA steel for better continuous welding * Welding technology and material selection for fuel tank * Steel evaluation for tailored blank use * Quality control technology for sound joining * Welding and material design for wheel rim (steel/aluminum) * Road wheel rim material evaluation
Arc welding * Shield arc welding * Gas arc welding	* Recommendation of optimum welding condition * Proposal of welding gas composition for underbody parts
Laser beam welding (CO_2) (YAG)	* Selection of material for tailored blank use * Welding and material design for coated steels

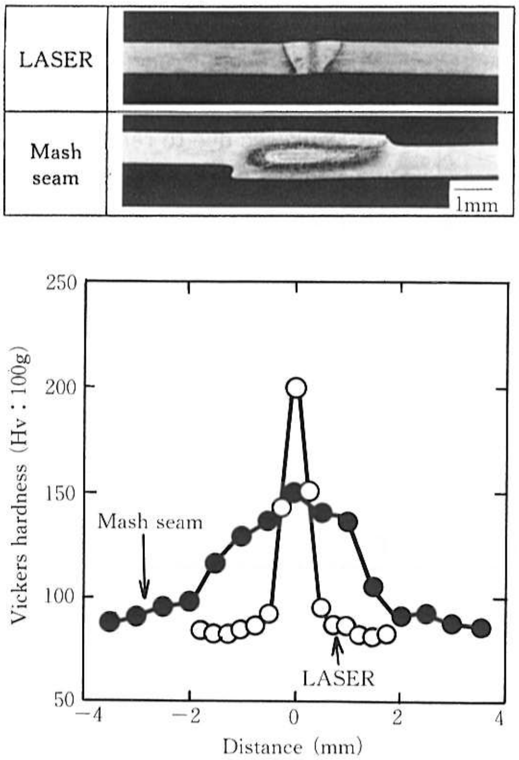


Fig. 8 Cross-sectional shape and hardness of LASER or mash-seam welded portion

5.3 Corrosion Resistance

The various coated steel steels were born and improved through a joint research with customers, as have been described. **Table 4** shows research equipment and some related results. Various simulation for phosphating, painting, and a variety of corrosion test cycles can be performed. For example, the corrosion resistance deterioration is caused sometimes by incomplete phosphating. **Figure 9** shows SEM micrographs before and after Cu deposition treatment for phosphated sheet. Cu is deposited to the area where phosphating is incomplete[25),26)]. This measure is used as a simple evaluation of the materials for phosphating.

5.4 Fatigue Strength

SMI's particular anti-fatigue technologies about railway wheels and axles have been utilized for the weight reduction trials of road wheels. As the result, between 450 and 550 MPa grade high strength steels are being used for road wheels. The reason why the higher strength steel is not used is

Table 4 Typical experimental equipment and application for corrosion assessment

Test method	Characteristic application of the test
Phosphating test	* Assessment of phosphatability for arc-welded portion * Easy assessment of phosphatability by Cu deposition
Swing-panel corrosion test	* Test in various wet atmosphere with single test piece * Cyclic corrosion test under absorbable iron rust
Gas corrosion test	* Acid rain/air pollution simulation
Cut-edge corrosion test	* Various burr height effect test by single test piece
Electro-deposition test	* Simulation of cratering and various paint defects
Scanning vibration electrode test (SVET)	* Micro-defect detection by electro-chemistry method
Overlapped portion test	* Corrosion simulation at sheet gaps near welded portion

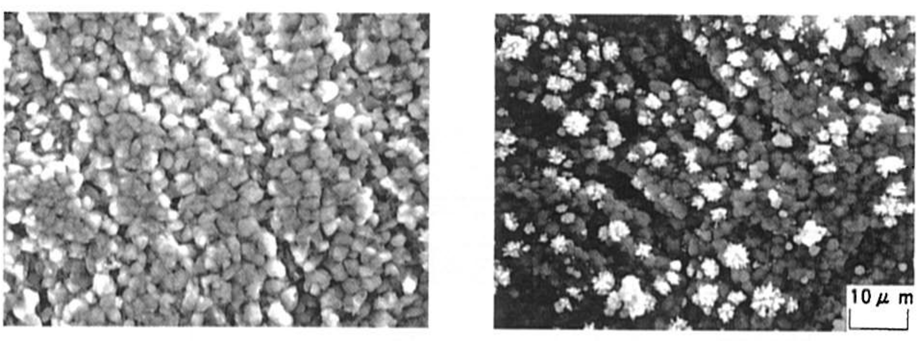


Fig. 9 Simple evaluation method of incomplete phosphate film by Cu deposition method (SEM micrographs before and after Cu deposition)

that, as shown in **Fig. 10**, though the fatigue life measured by flat test piece increases as the strength increase, the fatigue life of actual road wheel parts levels off at about 550 MPa of material strength[27),28)]. By the examination of the crack initiation, the residual stress and work-hardening of materials and shape and finish of ventilation holes were realized to be important and thus the information were applied in improving the fatigue life.

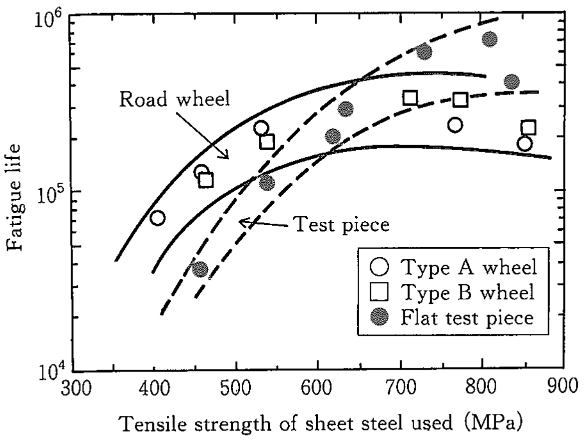


Fig. 10 Effects of tensile strength on fatigue life of actual road wheel and flat test piece

5.5 Crash Worthiness

The examination in high speed tensile testing and impact collapse test has been progressed recently for the material request for frontal crash worthiness vehicle. The test equipment is given in **Table 5**. As for the high-speed tensile testing, one bar method is useful in measuring accurate stress strain curve at a maximum rate of $2x10^3$/sec due to relatively larger specimen, as shown in **Fig. 11**, than Hopkinson-bar method. For a welded column specimen, a high-speed collapse test is performed at a constant cross head speed of 4 m/sec, as shown in **Fig. 12**. From the stroke-load curve examination, it was found that the component made of retained austenite steel of 590 MPa grade showed the largest energy absorption among the steels examined[10)].

6. Conclusion

The sheet steels for automobile have advanced largely from the age of rimmed steels. Today the various kinds of developed steels are integrated and to be standardized to a certain kind. Though it appears to be an ultimate figure for sheet products, the products and technology shall certainly change corresponding to the market and social demand. Therefore the joint research of application technology with customers and the product development which meets the customer's needs in advance are becoming more and more necessary for steel industries.

Table 5 High speed deformation test equipment

Test method	Characteristic of the test equipment
One bar high speed tensile test	Sample : 10 mm wide, 20 mm long Test speed : $2x10^3$/sec (about 144 km/hr)
High speed compression test for assembled parts	Cross head speed : 4m/sec (about 14 km/hr) Maximum load : 150 tonf

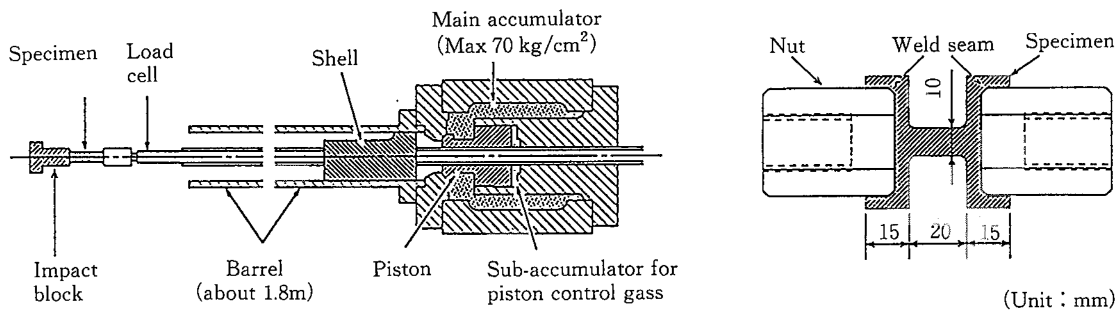
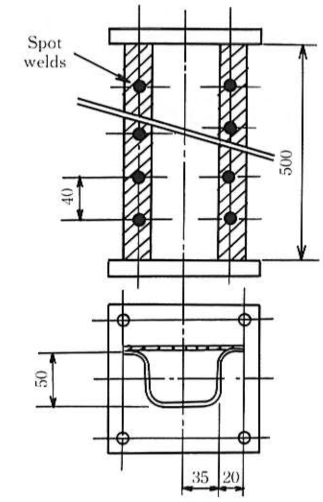


Fig. 11 Schematic illustration of apparatus and specimen for one-bar high speed tensile test method



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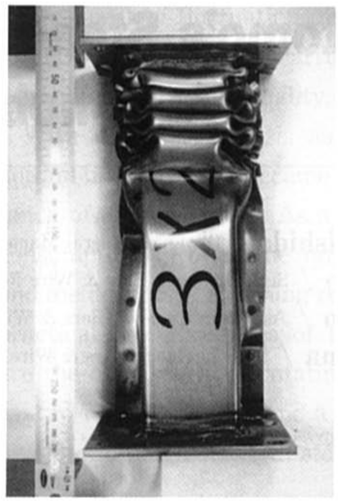

Fig. 12 Illustration of model column specimen for high speed collapse test and appearance of collapsed column

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