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Vision of Application Technologies for High Strength Steel Sheets Supporting Automobile Weight Reduction†

YOSHITAKE Akihide[*1] YASUDA Koichi[*2]

Abstract:

Simulation and evaluation of automotive body structural performance using CAE are indispensable for expanding the application of high strength steel sheets as a means of promoting weight reduction in automobile. JFE Steel has established a new environment for these application fields in order to establish Early Vendor Involvement (EVI) for automotive makers. As examples of application technologies supporting expanded use of high strength steel sheets, this paper introduces prediction/evaluation technologies using analytical techniques and joining techniques, as well as related systems which develop these technologies, and also describes part of JFE Steel's efforts in application evaluation technology.

1. Introduction

Against the background of prevention of global warming and recent sharp increases in crude oil prices, expanded use of high strength steel sheets is expected in viewpoint of weight reduction of automotive body and securing and improving crashworthiness. However, the formability of the material itself tends to decrease as strength increases. Accordingly, in order to respond quickly to the requirements of automobile makers and parts makers who are attempting to positively apply high strength steel sheets to automotive structural parts, not only material supply, but also support in the view of forming technology is necessary and indispensable. JFE Steel's Steel Research Laboratory began development of new forming technologies of this type in fiscal year 2003.

Considering both total capabilities in the area of materials/forming technology and part manufacturing costs, JFE Steel is also positively developing "cooperative creation" activities and Early Vendor Involvement (EVI) activities aimed at quick development of automotive parts through mutual cooperation between the material maker and both automotive makers and parts makers from the design stage. As part of these efforts, JFE Steel established the industry's first Customers' Solution Laboratory (CSL), which focuses on the automotive field, in the Steel Research Laboratory, Chiba District in Aug. 2005, and launched a joint venture company, JEVISE Corp., in June 2005 with the German company ThyssenKrupp Steel AG in order to continue a comprehensive technical tie-up in the field of automotive engineering. JFE Steel is actively engaged in a dialogue with engineers from the design divisions of many automotive makers and parts makers, and plans to utilize new forming technologies using JEVISE Corp. to further deepen its EVI.

2. Use Evaluation Technologies Supporting Automobile Weight Reduction

Weight reduction in automobiles has been realized by gaugedown of thickness and use of high strength steels in structural materials. **Figure 1** shows an example of a estimation of the weight reduction effect when high strength steel sheets are adopted in certain parts. The main assumptions in the estimation of the respective cases were as follows:

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*1 Dr. Eng.,
General Manager, Forming Technology Res. Dept.,
Steel Res. Lab.,
JFE Steel

*2 Dr. Eng.,
Principal Researcher General Manager,
Steel Res. Lab.,
JFE Steel

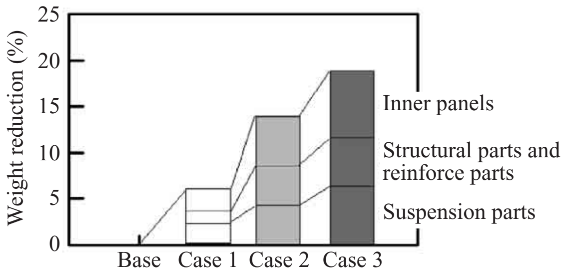

Fig. 1 Effect of weight reduction of automotive body by using high strength steel sheets

Case 1: Structural parts and reinforcements are mainly 590 MPa grade materials; exposed panels are 390 MPa grade.
Case 2: Structural parts and reinforcements are mainly 780 MPa grade materials; exposed panels are 440 MPa grade.
Case 3: Structural parts and reinforcements are mainly 980 MPa grade materials; exposed panels are up to 590 MPa grade.

From these estimations, even if the strength of the materials used is positively increased, the weight reduction effect is up to 20%, and it is expected to be difficult to achieve the 25–30% weight reduction level which automotive makers are currently targeting. Accordingly, it is necessary to implement weight reduction in combination with change in shape of the body structure. An indispensable requirement for this is the development of techniques for predicting body structural performance using CAE (CAE: Computer-assisted engineering, an engineering technology for evaluating the feasibility of parts and evaluating and predicting the crashworthiness and stiffness of the automotive body using analytical techniques, and particularly the finite element method (FEM)).

Against this background, JFE Steel is positively promoting EVI activities by combining material proposals for automobile weight reduction with proposals related to the body structure. In these activities, the material maker initiates a dialogue from the design stage of the body structure and part, including structural changes and material changes aimed at maintaining and improving required properties, and carries out joint development with the automotive maker/parts makers. The purpose of these activities is not limited to the conventional simple supply of materials and evaluation of press formability, but encompasses a full range extending to the properties of the parts, the performance of the automotive body, and mass production (**Fig. 2**). The required evaluation and prediction techniques should cover a far wider range, and the accuracy required in these technologies becomes higher. Furthermore, improvement of evaluation devices and measuring devices to verify the required accuracy is also being implemented in parallel with the above.

3. Analytical Techniques (CAE)

CAE is a technology which has progressed and been applied rapidly in recent years because it enables evaluation/verification on a computer without costly experimental verification. Because convincing proposals utilizing this type of analytical technique are necessary and indispensable in cases where a material maker argues the suitability material which is to be applied to an automotive body, JFE Steel has continuously developed its own proprietary analytical techniques. This chapter will introduce the evaluation of press-forming, which has been the most frequently used technique in evaluations, and analytical techniques for the crashworthiness evaluation properties of parts, and will describe their importance and necessity.

In evaluations of the press-formability of automotive steel sheets, evaluation is generally performed using the forming limit diagram (FLD) of the material. The strain

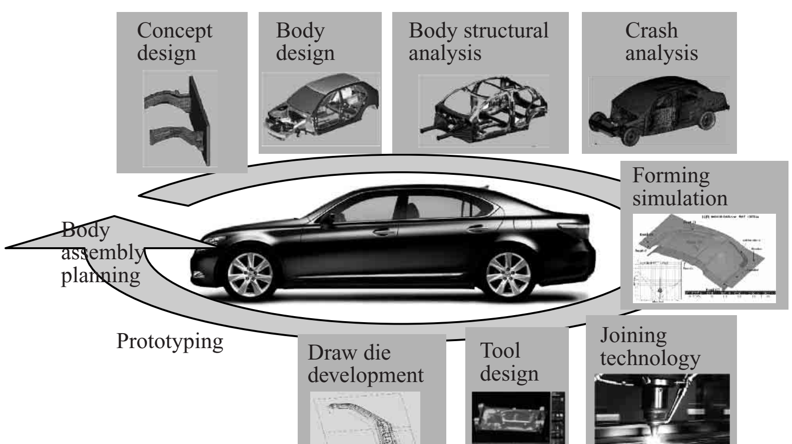

Fig. 2 Technology fields in early vendor involvement from JFE Steel

distribution in various area of pressed parts is estimated by CAE analysis. Therefore, press-formability of the material can be evaluated by comparison between strain distribution and FLD. On the other hand, the accuracy of predictions of the strain distribution in pressed parts by analytical techniques will not agree precisely if the detailed conditions in actual press operation are not reflected accurately. These include, for example, the bead shape, the friction behavior of the material with the die, blank holding force (BHF) conditions, and others. Furthermore, in cases where only the product shape is known and the shape of the die is unknown, or under conditions where the die shape is known but is modified subsequently by die ajusting, analytical accuracy will be poor. Thus, it can be said that a close exchange of information between the user and the die maker concerning press forming is the key to predictive accuracy. Where the FLD characteristics of materials are concerned, JFE Steel has already constructed a database for each material using its own evaluation methods, and its accuracy is superior to that of the prediction models generally used.

The accuracy of crashworthiness evaluations of parts may be mentioned as an example of the accuracy of predictions of part properties[1]. In the 1990s, when automobile weight reduction received intense attention and research on improvement of crashworthiness using high strength materials was active, a great deal of research was done on material properties in the strain rate region corresponding to collision phenomena[2]. **Figures 3** to **5** show the results for a hat column, which is a typical shape of the reinforcement. Figure 3 is an example of stress-strain curve in which the strain rate dependency of material strength was evaluated accurately by a high speed tensile test device, and the crashworthiness of the part was evaluated using this property (Figs. 4, 5). The importance of considering the strain rate dependency of material strength in improving crashworthiness predictions can be understood well from these results. At JFE Steel, efforts are not limited simply to the development of analytical techniques, but also include verification of

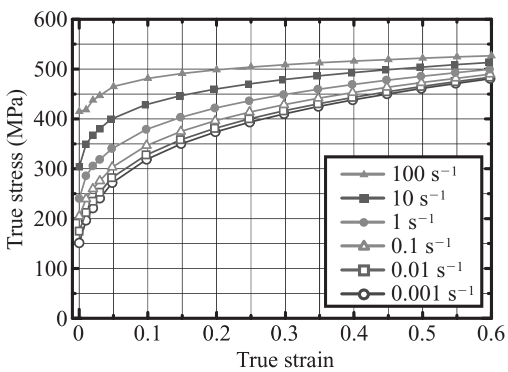

Fig. 3 Strain rate sensitivity of stress-strain curve of mild steel

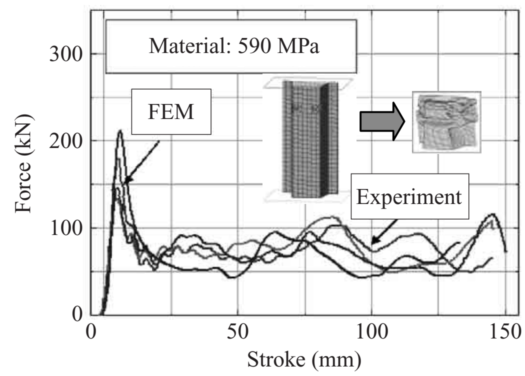

Fig. 4 Estimation of Crash behavior by using CAE

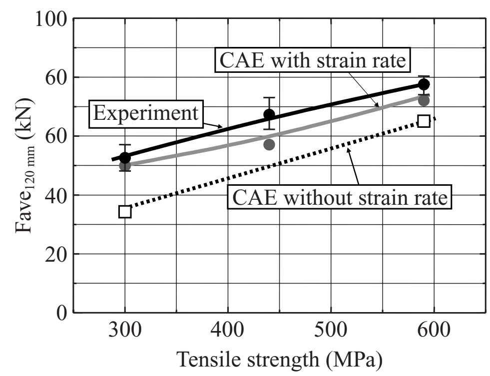

Fig. 5 Accuracy of CAE estimation with/without strain rate effects

their accuracy by comparison of analytical accuracy with experiments and accumulation of results. These techniques are also reflected in evaluations of actual automotive parts and body crashworthiness, and are expected to be actively used in the future as added value in EVI activities.

It can be said that the accuracy of press-forming analysis techniques has reached a quite high level, but many problems still remain. For example, although defects such as cracking and wrinkles can be predicted, adequate prediction of stretch-flangeability is not possible. At present, prediction techniques of this type are being actively developed, and it is expected that the development of a sufficiently accurate technique for evaluating the formability of parts requiring stretch-flangeability, such as suspension arms, side panel outers, and others will be possible in the near future.

4. Experimental Evaluation Techniques

The Steel Research Laboratory developed a new forming technology (JFE Intelligent Multi-stage Forming with Press Motion Control; Trade name: JIM-Form) with the aim of expanding the application of automotive high strength steel sheets to hard-to-form parts, and began trial-manufacture research and development of parts as a step toward practical application[3–5]. As a distinctive feature of this technology, pressing is performed while controlling the forming stroke so as to avoid excess press load by optimizing the friction behavior between the sheet and the die in the press forming process. In the past, a method of forming in steps, in which only the punch stroke in the forming process was controlled, and a method of improving formability by punch vibration were reported[6–9]. However, JIM-Form is the newly developed forming method which attempts to expand the forming limit by linkage with friction behavior. Fundamental small-scale deep-drawing experiments using 780 MPa grade high strength steel sheets clarified the fact that it is possible to reduce the maximum press load at a given blank holding force (BHF) by approximately 10%, and thereby improve the forming limit characteristics of the material by a corresponding amount. Thus, application of this technology will make it possible to apply materials with strength up to 980 MPa, even with hard-to-form products which could only be press-formed with 780 MPa grade materials in the past.

In order to control the forming stroke using this technology, it is necessary to make full use of the functions of the servo press machine. Therefore, a 300 t class servo press (**Photo 1**) was introduced in the Steel Research Laboratory, Chiba District, and research toward practical application began.

The features of JIM-Form are as follows.

(1) The press-formability of high strength steel sheets can be increased substantially, and it is possible to expand the application of high strength steel sheets to automotive parts in which application was difficult for conventional press-formability.

Photo 1 Servo press machine installed JIM-Form technology

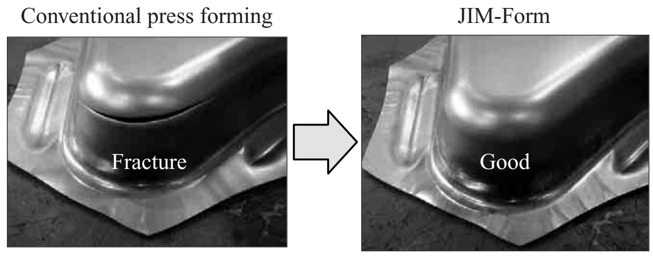

Photo 2 Effect of JIM-Form Technology as compared with conventional press forming

(2) In application to conventional deep-drawing parts, in which deep drawable steel sheets are generally used, JIM-Form contributes to stable production of press-formed parts and expanded freedom in parts design by improement of formability.

(3) Automation of JIM-Form is possible by combining the servo press machine, which enables free control of the sliding operation of the press machine, and a die cushion system; as a result, in comparison with the conventional press-forming method, productivity is not greatly reduced, and application to mass production technology, including automotive parts, etc. can be realized with comparative ease.

Forming technology for high strength steel sheets has been dramatically improved by the development of innovative servo equipment, and it is becoming possible to apply these materials to hard-to-form products which had been considered impossible until now (**Photo 2**). The development of this type of forming technology is an key technology for further advances in automobile weight reduction, and active promotion as a technology which increases added value in material proposals in parallel with improvement of material properties is planned.

5. Welding Technology

Welding technology has become important for effectively utilizing high strength steel sheets. This chapter will present an outline of welding technologies developed independently by the Steel Research Laboratory.

In welding for assembling automotive bodies, resistance spot welding has been the most widely used for the past several decades. Recently, in some structural parts, the total sheet thickness (exposed panels + reinforcements + inner panels) has become thicker relative to the thin exposed panels due to the use of high strength materials and increases in sheet thickness in reinforcements and inner panels. Such kind of sheets combration is difficult to weld by conventional resistance spot welding. JFE Steel solved this problem by developing a new welding process called “Intelligent spot welding technology”[10] which realizes “2-step electrode force and 2-step welding current control” by using a servo motor driven servo gun type welder. In quality inspections of spot welds, evaluation test method in which quality was judged by direct observation of spot welds, which was opened by a wedge-shaped chisel, has been used in common. However, there are some problems in the case of high strength and thick sheets welded joint, in that it is impossible to insert the chisel between the sheets or the crack initiates in welded portion when the sheets are opened with the chisel, resulting in reduced strength. To solve these problems, JFE Steel developed an ultrasonic nondestructive inspection technology using the plate wave transmission technique.

In addition to application of high strength steel sheets, increased joint strength is also desired as a means of achieving weight reduction. Because laser welding is a continuous process, it is known that this technique not only increases stiffness and static/fatigue strength, but also greatly improves impact strength in comparison with spot welding, and therefore increases the effectiveness of applying high strength steel sheets for weight reduction of automotive bodies. Laser welding and brazing are already widely used in automotive body production in the Volkswagen AG Group[11]. For example, in the Volkswagen Golf V, laser welding is applied to approximately 45% of the total weld length in the automotive body. As a result, 35% increase in bending stiffness and 80% increase in torsional stiffness have been confirmed. In addition to this dramatic improvement in performance, a variety of large cost merits have also been reported, including a reduction in manufacturing man-hours, reduction of thermal strain, reduction of assembly plant space, etc.[11] However, application of laser welding had been limited by the high cost of the equipment itself, issues related to production control, such as the fact that the gap between sheets must be strictly controlled within approximately 0.2 mm or less because the process is prone to melt-down, and quality-related issues[12] such as blowholes in lap welding of Zn-coated steel sheets. To solve these problems, JFE Steel developed the "Laser-Arc Hybrid Welding Technique,"[13] which is hybrid of YAG laser and arc welding methods. As merits, this technology increases the allowable gap between sheets in comparison with the conventional laser welding method, reduces blowholes even in lap welding of Zn-coated sheets, etc. In addition, because an arc is used in combination with a laser, the width of the weld is larger, and as a result, this technology also has the performance-related merit of increasing static, fatigue, and impact strength.

Gas metal arc welding is used in welding of suspension parts. In this application, there are a few problems as follows:

(1) In the quality aspect, appearance and paintability are reduced by spatter.

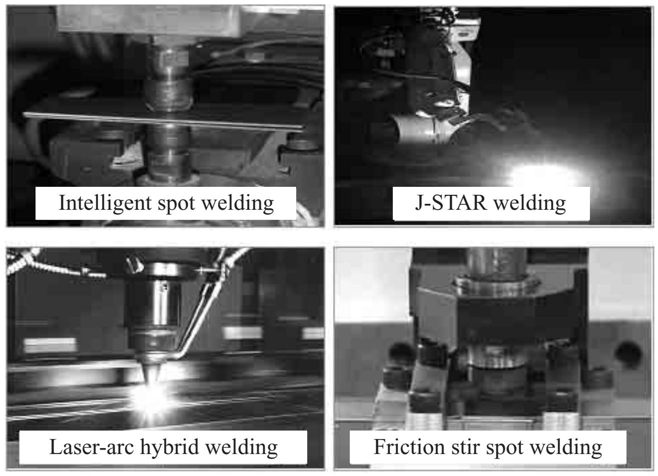

Photo 3 Newly developed welding technologies for assembly of automotive body

(2) From the viewpoint of joint quality, the fatigue strength of the arc welded joint is virtually the same even if the strength of the material is increased, and the fact that there is little merit in applying hig-strength steel sheets is a problem.

The "J-STAR Welding Technique"[14] was developed to solve these problems. In this new arc welding technique, the amount of spatter generation is reduced to less than 10% by adding REM to the welding wire as an arc accelerator and using a positive polarity, which is opposite that in the conventional gas metal arc welding. Furthermore, combined to plasma welding, a new welding process[15], which can achieve smoothing weld toes and a large improvement in fatigue strength, had been developed.

As future technologies, JFE Steel is also developing new joining techniques such as friction stir spot welding (**Photo 3**) in anticipation of needs which may appear in the future, including, for example, hard-to-weld materials and combinations, etc.

6. Customers' Solution Laboratory (CSL)

JFE Steel established a joint development system for positive technical public relations to automobile makers and joint development of parts and bodies. In Aug. 2005, the company established the Customers' Solution Laboratory (**Photo 4**) in the Steel Research Laboratory, Chiba District as a platform for a dialogue on future automotive manufacturing. In the period of approximately 2 years to date, the center has received over 1 000 visitors and is concretely promoting significant discussion and joint development items. As a distinctive feature of this facility, the CSL has become possible to explain all of JFE Steel's activities related to automotive fields. This in turn has made it possible to respond quickly and flexibly to the issues facing customers. As part of JFE

Photo 4　Customers' Solution Laboratory (CSL)

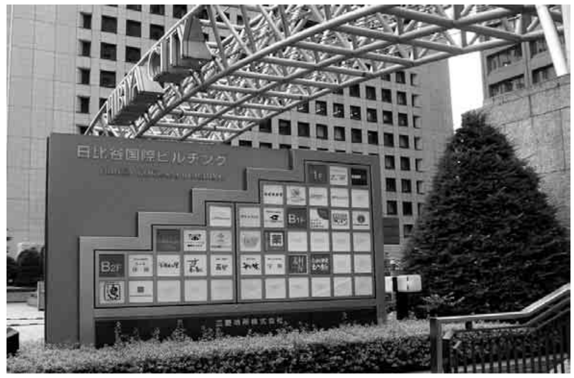

Photo 5　Location of JEVISE Office

Steel's efforts to enable discussions which anticipate the future needs of automobile manufacturing, the CSL also includes exhibits of highly confidential materials technologies and evaluation equipment, etc. which are currently under development, in addition to exhibits of materials and equipment currently being produced. In an era when ever-increasing importance is attached to shortening the development period, a constant dialogue with the customer is necessary and indispensable for grasping the customer's needs at the earliest possible timing and responding quickly to them. Thus, as a material maker, JFE Steel plans to promote these activities in the future in order to propose high strength steel sheets which can contribute to weight reduction of automotive body.

7. JEVISE Corp.

JEVISE Corp. was established in June 2005 as a joint venture with the German company ThyssenKrupp Stahl AG in order to create a global system for technical cooperation in the field of body engineering. The name JEVISE Corp. is an abbreviation for Japanese European Early Vendor Involvement Scheme Entity. The company's most essential purpose is to enable communication of information related to automotive materials as it concerns Japanese automotive makers, but broader objectives include effective mutual use of the two company's technologies and resources related to engineering in automotive manufacturing, and rapid development of EVI activities responding to globalization by automotive makers. The composition of the company's employees comprises 50% dispatched personnel from JFE Steel and ThyssenKrupp AG, respectively. The company is located adjacent to JFE Steel's Head Office (**Photo 5**). The purpose of the EVI proposed by JEVISE Corp., as shown in **Fig. 6**, is not the analysis/evaluation business or service business related to material supply performed by conventional material makers, but rather, positive proposals for weight reduction and automotive body property evaluations by the material, maker from the design stage of automotive body development with the automotive maker's designers. To date, ThyssenKrupp Stahl AG has been possible to make weight reduction proposals and cost reduction proposals using body structure manufacturing technologies cultivated in Europe over the course of many years, and in particular, manufacturing and evaluation technologies including tailor welded blanks (TWB), laser welding technology, hydroforming technology, roll forming technology, structural optimization techniques, manufacturing cost calculation techniques, and others. Thus, the activities of JEVISE have become necessary and indispensable for promoting JFE Steel's EVI activities.

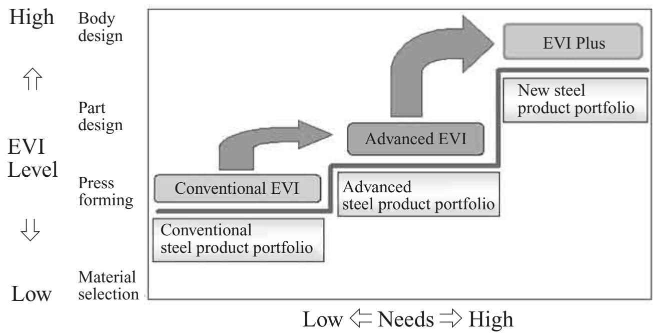

Fig. 6　EVI levels proposed by JEVISE Corp

At present, when Japanese auto makers are expanding globally and beginning to produce automobiles throughout the world, the ability of the material maker to mutually share information with the automotive maker and make proposals related to automotive manufacturing from a common viewpoint is advantageous to both the automotive maker and the material maker. In particular, JFE Steel is confident that it can respond efficiently to the need to shorten the startup period in overseas production by Japanese automotive makers.

8. Conclusion

As examples of application technologies supporting expanded application of high strength steel sheets, this paper has introduced prediction/evaluation techniques using CAE, joining techniques, and related systems for the expansion of these techniques, and has also described a portion of JFE Steel's efforts in the area of use evaluation technology. In the future, JFE Steel plans to make active efforts in parts development and automotive body development through a close dialogue with automotive makers and parts makers.

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