

Development of high strength steels with high press formability and fatigue property

H Shuto¹, Y Ito², D Maeda² and T Yokoi¹

¹ Nippon Steel & Sumitomo Metal Corporation, 1 Oaza-Nishinosu, Oita City, Oita Prefecture, 870-0992, Japan

² Nippon Steel & Sumitomo Metal Corporation, 20-1, Shintomi, Futtsu City, Chiba Prefecture, 293-8511, Japan

E-mail: shuto.87e.hiroshi@jp.nssmc.com

Abstract. High strength steels with good press formability and high fatigue strength were developed by NSSMC. They are hot-rolled steels of tensile strength grade of 590-780 MPa. They have high elongation and fatigue property as DP steels, and have higher hole expansion ratio than the DP steels and conventional HSLA steels. In this study, press formed automotive parts made from the developed steels were compared with those by using the DP steels and the conventional HSLA steels. To compare the press formability, the steels were pressed into lower-arms by bend flange with a pad method. Height of flange was changed to control the effort required for the press forming. In the case of flange height of 14.5mm, the developed steels were able to be formed without cracks. However, there were some cracks when the DP steels and the conventional HSLA steels were used. Since the cracks were initiated at the region where stretch-flangeability was needed, the developed steels are thought to be applicable to the parts which require high stretch-flangeability. To compare the fatigue strength, plane bending fatigue tests and coaxial low cycle fatigue tests were conducted. The plane bending fatigue tests showed that fatigue strength of the DP steels and the developed steels were superior to those of the conventional HSLA steels between 10^4 to 10^7 cycles. Low cycle fatigue tests indicated that although the conventional HSLA steels exhibited fatigue softening, the DP steels and the developed steels showed fatigue hardening.

1. Introduction

High tensile steels for automobiles have been developed rapidly over the past decades, in order to reduce weight of vehicles without decreasing collision safety. For example, Nippon Steel and Sumitomo Metal Corporation have developed 1180 MPa grade cold-rolled steel [1], and 1800 MPa grade steel for hot stamping [2-4]. These steels have been applied for structural parts of car body, and have contributed to reduce the body weight. However, in the case of chassis parts, tensile strength of the steels is lower compared to the structural parts. In order to reduce the weight of the chassis parts, we have developed 590–780 MPa grade hot-rolled steels. In this study, we report some property of the 590 MPa grade hot-rolled steels.

The hot-rolled steels used in the chassis parts are required several property. First, high stretch flangeability is important to form complicated parts so as to improve effectiveness and stiffness of the parts. Second, fatigue strength is essential since severe cyclic stresses are imposed to the chassis parts during driving. Furthermore, corrosion resistance is required because the chassis parts are often used in wet and salty environment. Finally, arc-weldability is necessary to fabricate the chassis parts.



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Since our new developed hot-rolled steels satisfy these demands, we assure that we can contribute to the reduction of the weight of the chassis parts. Figure 1 shows total elongation and hole expansion ratio of the developed steels. Hole expansion ratio is an index of the stretch flangeability. The developed steels have higher stretch flangeability than DP steels without decreasing total elongation, so that they can form more complicated parts as mentioned later.

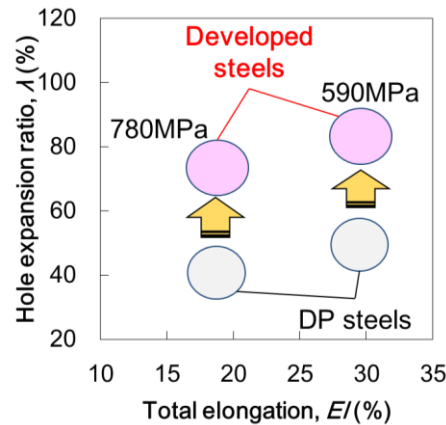


Figure 1. Press formability of developed steels and DP steels.

2. Press formability of developed steels

2.1. Experimental procedure

To investigate the effect of superior press formability of the developed steels, press forming tests were conducted. Table 1 shows mechanical property of samples used in this study. The developed steel, (Steel A), the DP steel (Steel B) and the conventional HSLA steel (Steel C) were selected because they have different press formability respectively. The thickness of the steels is 2.6 mm, and the tensile strength of them is 620 MPa.

These steels were cut to blanking sheets and were pressed to lower-arms by bend flange with a pad method as shown in Figure 2. Height of the flanges was changed from 13.0 mm to 14.5 mm to control the difficulty of stretch flange forming. After the press forming, the flanges were checked whether cracks were initiated or not.

Table 1. Mechanical property of samples used in this study. Steel A corresponds to the developed 590 MPa steel.

Steel	Thickness (mm)	Tensile strength, TS (MPa)	Total elongation, E_l (%)	Hole expansion ratio, λ (%)
A	2.6	620	30	100
B	2.6	620	30	80
C	2.6	620	22	80

2.2. Result

Figure 3 represents photographs of lower-arms formed with a flange height of 13.0 mm. Although Steel A and Steel B are formed successfully, Steel C is cracked in a stretch flange area. Lower-arms formed with a flange height of 14.5 mm are shown in Figure 4. There is no crack in Steel A, but cracks are initiated in Steel B and Steel C. These results show that more complicated parts are able to form with the developed steels because of their high stretch flangeability.

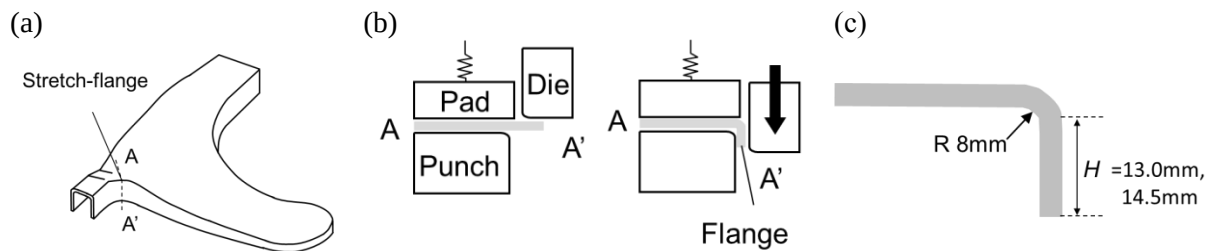


Figure 2. How to press the lower-arms. (a) Schematic sketch of the lower-arm parts. (b) Explanation of bend flange with a pad method. (c) Enlarged illustration of stretch flange area.

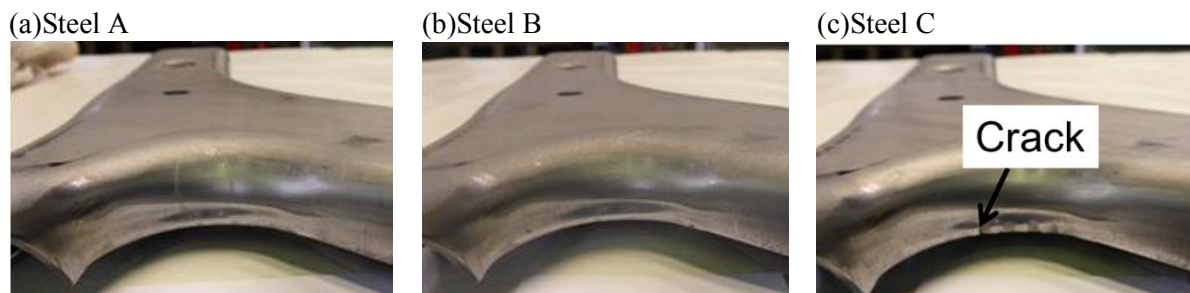


Figure 3. Pictures of stretch flange area with a flange height of 13.0 mm.

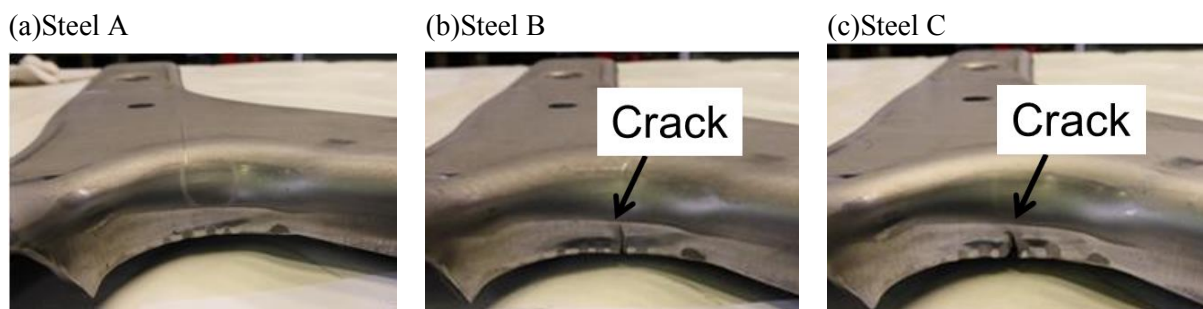


Figure 4. Pictures of stretch flange area with a flange height of 14.5 mm.

3. Fatigue strength of developed steels

3.1. Experimental procedure

Steel A, B, C were used again to evaluate the fatigue strength of the developed steels. To exclude surface layer effects, the front and back surface were grinded and electropolished. Then, a gage length of 9 mm dog-bone shaped fatigue specimens were cut from the steels. Push-pull fatigue tests were conducted with total strain amplitude of 3×10^{-3} , 4×10^{-3} and 5×10^{-3} at a strain rate of $4 \times 10^{-4} \text{ s}^{-1}$. Based on hysteresis loops at a half cycle of the fracture, cyclic stress-strain curves were plotted as shown in Figure 5. By comparing cyclic stress-strain curves and stress-strain curves given by tensile tests, cyclic hardening / softening behavior of each steels is discussed. The surface of the samples during fatigue tests at total strain amplitude of 3×10^{-3} was observed to find out initiation sites of fatigue cracks.

3.2. Result

Figure 6 represents stress amplitude during cyclic deformation. Although Steel A and Steel B show a small decrease in stress as the number of cycle increases, stress amplitude of Steel C shows remarkable decrease. Marker x in the Figure 6 indicates stress at one half of the fracture cycles. By

connecting the marker coordinates, cyclic stress-strain curves are obtained. The cyclic stress-strain curves are plotted in Figure 7 with stress-strain curves obtained by tensile tests. In Steel A and Steel B, the cyclic stress-strain curves indicate stress that is equal to or higher than the stress-strain curves obtained by tensile tests. It means that cyclic hardening is occurred in Steel A and Steel B. On the other hands, the cyclic stress-strain curve of Steel C is lower than the stress-strain curve obtained by a tensile test. Since cyclic hardening materials have higher resistance to cyclic deformation, Steel A and Steel B are considered to have higher fatigue strength than Steel C from the view point of cyclic softening / hardening behavior.

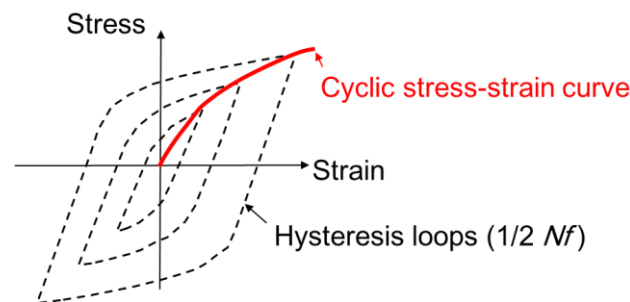


Figure 5. Definition of cyclic stress-strain curve in this study.

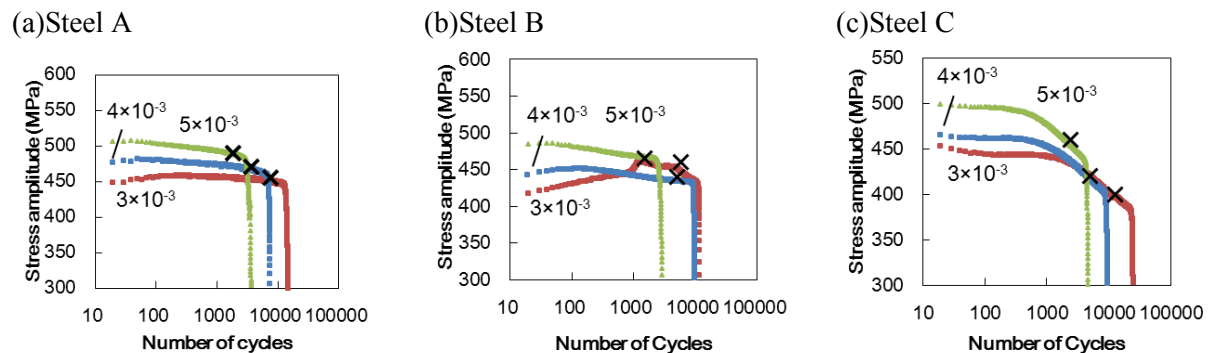


Figure 6. Stress amplitude during fatigue tests. Numbers in the Figures represent total strain amplitude.

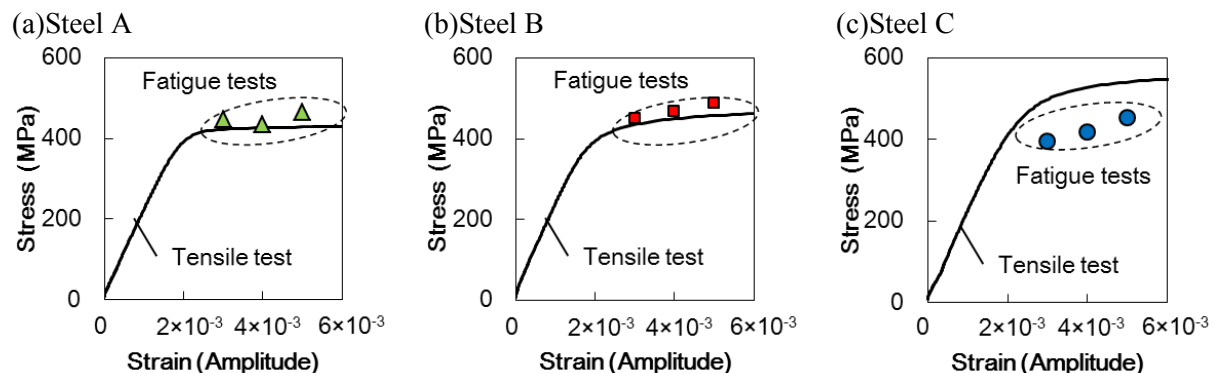


Figure 7. Comparison of cyclic stress-strain curves obtained by fatigue tests and stress-strain curves obtained by tensile tests.

Figure 8 shows the surface of the specimen before and during fatigue tests at total strain amplitude of 3×10^{-3} . Tensile axis is indicated by an arrow. Before the fatigue tests, there is no fatigue crack at the surface of the samples. After 4000 cycle deformation, fatigue cracks are observed in Steel C as shown in Figure 8 (f). Since these fatigue cracks are initiated from cementite particles precipitated in grain boundary, restraining the precipitation of these cementite particles is effective to improve fatigue strength. The amount of the cementite particles in Steel A are reduced as a result of careful controlling of chemical composition and cooling pattern. It is one of the reasons why the developed steels have good fatigue strength.

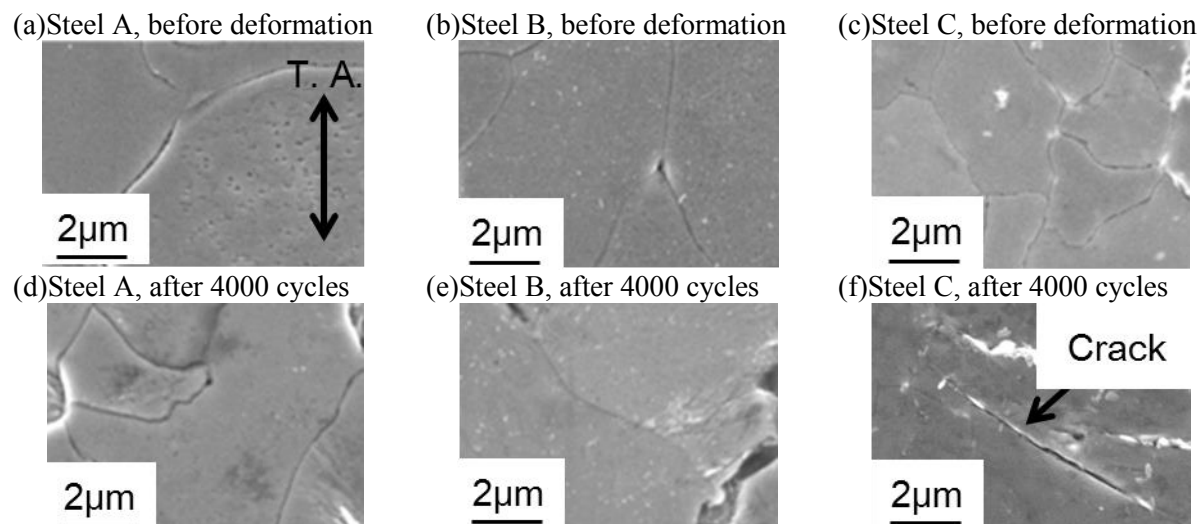


Figure 8. SEM observation of the specimen surface before and during fatigue tests.

4. Chemical conversion treatment of the developed steels

4.1. Experimental procedure

In order to improve corrosion resistance, chassis parts are usually covered by chemical conversion coat. Thus, quality of chemical conversion coat after chemical conversion treatment is important for hot-rolled steels to satisfy the corrosion resistance required for the chassis parts. To check the quality of the chemical conversion coat, chemical conversion tests were carried out on Steel A and Steel B. Zinc phosphate coating was used because it is the most commonly used coating for the chassis parts. After coating, surface of the coat was observed by SEM, and coating weight was measured using X-ray diffraction method.

4.2. Result

Figure 9 shows the surface of the specimens after the chemical conversion tests. The zinc phosphate coat covers the entire surface, so that there is no exposed steel surface. Sizes of the zinc phosphate particles are comparable between Steel A and Steel B. Figure 10 represents the coating weight of the samples measured by X-ray diffraction method. This figure indicates that the coating weight of Steel A is as high as Steel B. These results suggest that the quality of zinc phosphate coating of the developed steels is comparable to that of conventional steels. Additionally, we have performed salt spray tests and cyclic corrosion tests, and confirmed that the corrosion resistance of the developed steels is as high as the conventional steels.

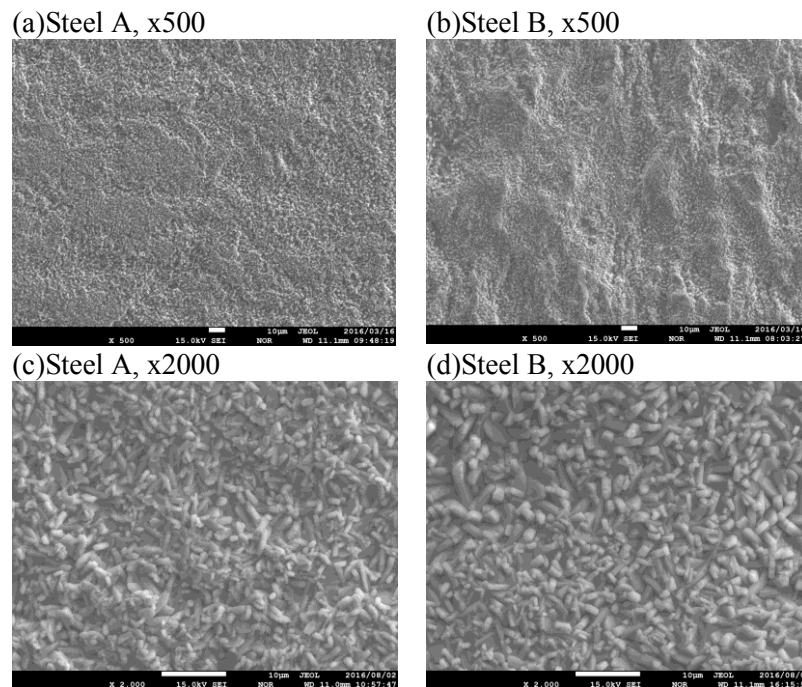


Figure 9. SEM observation of the zinc phosphate coating.

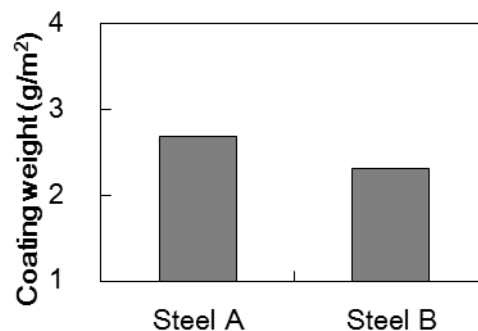


Figure 10. Weight of the zinc phosphate coating measured by X-ray diffraction method.

5. Conclusion

590–780 MPa grade hot-rolled steels have been developed by Nippon Steel & Sumitomo Metal Corporation. These steels have higher press formability than conventional steels. In addition to this, the steels satisfy the required fatigue strength, corrosion resistance and arc-weldability for chassis parts. We assure that these steels can contribute to reduce the weight of the chassis parts.

References

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