Control of Microstructures and the Practical Properties of Thin-walled Hot-rolled High-Strength Steels

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In order to apply the thin-walled hot-rolled high-strength steels to the suspension parts with aim of reducing the automotive weight, the effects of microstructures and additional elements on formability of low carbon steels ware investigated. Microstructure of bainite were varied with both reheating and the transforming temperatures. The sample transformed at 350℃ after reheating at 1000℃ shows a typical upper bainite structure composed of bainitic ferrite lath and cementite between lath (Type B_{II}). The sample transformed at 450℃ after reheating at 880℃ shows another type of bainite, which is composed of carbide free bainitic ferrite lath and cementite aggregates (Type B_{I}). The bainite transformed at 300℃ after reheating 1000℃ seems B_{III} type bainite that has cementite platelets aligned in the interior of bainitic ferrite lath. It has revealed that the B_{I} type bainite that is composed of carbide free bainitic ferrite lath and cementite aggregates and is strengthened by solid solution is the best material in the combination of both stretchability and stretch-flangeability at the range of tensile strength 590 to 780 MPa. The superiority of Type B_{I} to Type FM and Type RA in stretch-flangeability is caused by the lower hardness ratio of the hard phase to the mild phase. On the other hand, the superiority of Type B_{I} to Type B_{II} in stretchability is caused by the lower hardness of the mild phase.

Keywords: *high-tensile hot-rolled steel, stretchability, stretch-flangeability, microstructure control, bainite, automobile suspension parts*

1. Introduction

The latest problem of automotive maker is energy efficiency of vehicles in order to preserve the environment. One of the methods to solve this problem is weight reduction of automobiles by using high-strength steels. For the automotive suspension parts, several types of hot-rolled high-strength steel sheets have been used, which are strenghthened by solid solution or precipitation. However, these types of steels are not sufficiently satisfied with the specific formabilities such as stretchability and stretch-flangeability.

To overcome this point, several types of hot-rolled high-strength steels have been developed these days, of which the microstructures are controlled utilizing thermos-mechanical treatment in a continuous hot-rolling process. One of these steels is composed of ferrite and bainite. It is the best microstructure for the case that is required both stretchability and stretch-flangeability in 540MPa in tensile strength. However, it is difficult to achieve the tensile strength over 590MPa level by this microstructure because of the shortage in strength.

At the range of 590 to 780MPa, two types of steels showing higher stretchability have also been developed, which are the steel composed of ferrite and martensite and the steel composed of ferrite, bainite and retained-austenite. Although these types of steels have improved in stretchability, stretch-flangeability is still remained as a problem to be improved. On the other hand, the steel composed of bainite shows excellent stretch-flangeability though stretchability is lower. Therefore, the preferable materials having both enough stretchability and stretch-flangeability in the tensile strength level over 590MPa are required to be developed by improving the bainite structure.

In this study[1)], the effects of the microstructures and the additional elements on the formability of bainite steels were investigated for the sake of achieving good combination of stretchability and stretch-flangeability over the tensile strength of 590MPa.

2. Experimental procedure

The chemical compositions of steels used in this study are listed in Table 1. The steel (A) was a mill product with 2.0mm thickness. The steels from (B) to (F) were melted by the vacuum furnace and hot-rolled in the laboratory. These steels were machined to the thickness of 2.0mm. the sulfur content was controlled below 0.005 mass% to eliminate sulfide inclusions.

Table 1. Chemical compositions of steel used

Steel	Chemical compsition (mass%)			
	C	Si	Mn	S
(A)	0.09	0.4	1.6	0.001
(B)	0.05	—	2.0	0.004
(C)	0.05	1.0	2.0	0.004
(D)	0.09	—	1.6	0.004
(E)	0.09	1.0	1.6	0.004
(F)	0.10	2.0	1.7	0.004

The steel (A) was heat-treated in a salt bath under condition shown in Figure 1 to obtain different types of bainite structures. The reheating temperature was varied from 880 to 1000℃ to change the austenite grain size. The isothermal transforming temperature was varied from 300 to 500℃ to change structures of bainite. The steels (B) to (F) were heat-treated under the condition of cycle 1 to investigate the effects of additional elements on strength and formability in the bainite steels. The reheating and the transforming temperatures were selected 880℃ and 450℃ respectively.

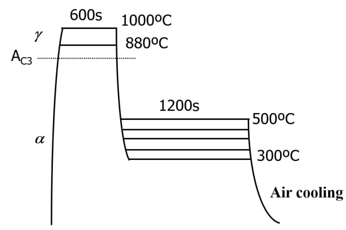

Figure 1. Heat cycles

Tensile tests were carried out using the JIS No.5 specimens. Stretch-flangeability was evaluated by the punched hole expanding test under the condition that the punch diameter is 10mm ϕ and the punched burr situated expanding die side. The microstructures were observed by SEM to analyze the bainite structure with microstructural parameters, such as lath width *d*, carbide density *n*, and diameter of bainite block *D*.

3. Results and Discussion

3.1 Effects of microstructures on formability in bainite steels

Microstructures of bainite were varied with both the reheating and the transforming temperatures as shown Figure 2. The sample transformed at 350℃ after reheating at 1000℃ shows a typical upper bainite structure composed of bainitic ferrite lath and cementite between laths (Type B_{II} [2)]), which is schematically illustrated in Figure 3. On the other hand, the sample transformed at 450℃ after reheating at 880℃ shows another type of bainite, which is composed of carbide free bainitic ferrite lath and cementite aggregates (Type B_I [2)]). The samples heat-treated on the intermediate conditions indicate the intermediate structures between the B_{II} and B_I. The samples transformed at 500℃ include a small amount of pearlite. The bainite transformed at 300℃ after reheating 1000℃ seems B_{III} [2)] type bainite that was cementite platelets aligned in the interior of bainitic ferrite laths.

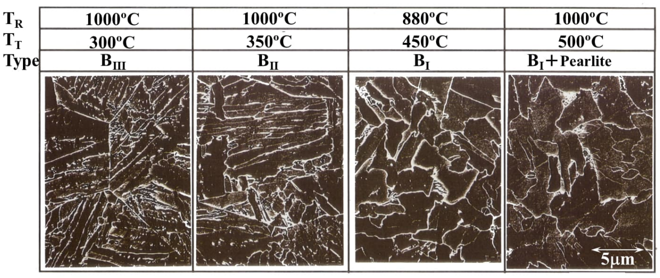

Figure 2. Effect of heat-treatment condition on bainite structure of steel (A)

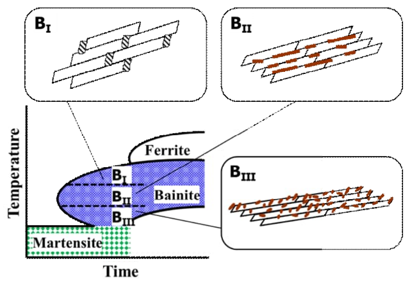

Figure 3. Schematic illustration of three types of bainite

The mechanical properties of specimens strongly depend on reheating and the transforming temperatures through the change of bainite structure as shown in Figure 4. Yield strength and tensile strength decrease with increase of transforming temperatures. On the other hand, elongation increases with increase of transforming temperature and with decrease of reheating temperature. The punched hole expanding ratio λ, shows a peak at 450℃. The decline of punched hole expanding ratio at 500℃ is apparently consistent with the presence of pearlite. Punched hole expanding ratio is higher at lower reheating temperature.

The microstructure of bainites ware specified by three microstructural parameters. These are lath width *d*, carbide density *n*, and diameter of bainite blocks *D*, which are schematically illustrated in Figure 5. The effects of the reheating and the transforming temperatures on these parameters are shown Figure 6. With increase of transforming temperature, the *d* increases and the *n* decreases, which leads the increase of elongation and punched hole expanding ratio and the decrease of tensile strength. The *D* is independent of transforming temperature and is determined by reheating temperature. The small *D* of the samples reheated at 880℃ is favorable for both high elongation and high punched hole expanding ratio.

Consequently, it can be confirmed that the fine B_I type bainite transformed at the higher temperature is a desirable microstructure for obtaining an excellent combination of high stretchability and high stretch-flangeability over the tensile strength of 590MPa.

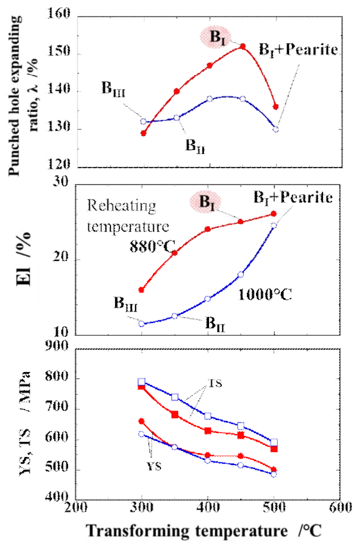

Figure 4. Effect of reheating and transforming temperature on mechanical properties in steel (A).

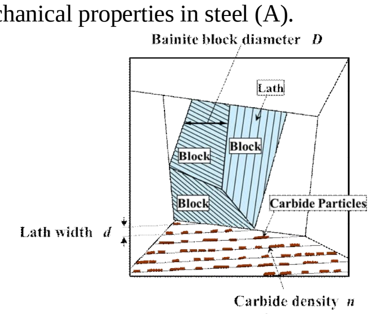

Figure 5. Schematic illustration of microstructural parameters in bainite

3.2 Effects of additional elements on formability and transformation behavior in bainite steels

The effects of additional elements on a balance of tensile strength and the formabilities are shown in Figure 7. The tensile strengths of the base C-Mn steels (B) and (D) are about 490MPa level. Addition of 1%Si leads the large increase of tensile strength by around 100MPa without any decline of punched hole expanding ratio and elongation. Addition of 2%Si also leads the increase of tensile strength preserving the same level of elongation. However, punched hole expanding ratio is comparatively deteriorated. In this steel, the retained austenite was detected about 7% in the X-ray diffraction measurement.

Additional Si content accelerates the bainite transformation during the continuously cooling after deformation of austenite[1], which is favorable to obtain Type B I structure in practical mill. Additional Si promotes the bainite transformation through retarding the recrystallization of the deformed austenite.

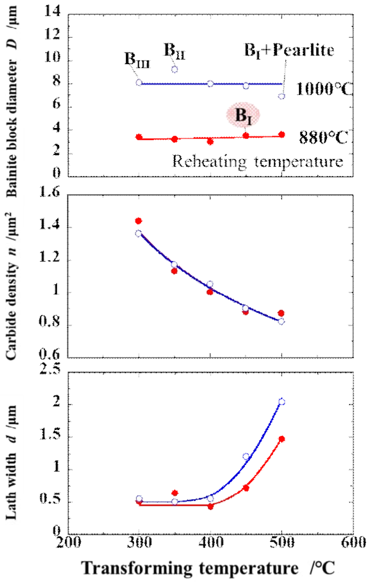

Figure 6. Effect of transforming temperature on microstructural parameters of bainite steel (A)

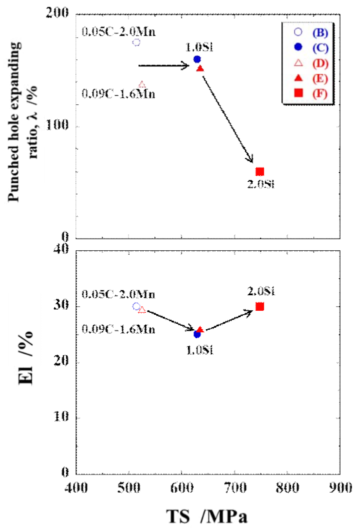

Figure 7. Effects of additional elements on mechanical properties of bainite

3.3 Comparison of developed steel to conventional steels

On the basis of these investigated results, the various high-strength hot-rolled steels with good combination of stretchability and stretch-flangeability in 780MPa level are summarize in Figure 8. The fine Type B I is the best material for the case that is required both stretchability and stretch-flangeability at the range of tensile strength 590 to 780MPa level for the application of suspension parts in automobiles.

Figure 9 shows the schematic illustration of the hardness of each phase that composes Type B_{II}, Type B_I and Type FM. It has already been clarified that stretchability can be improved with decrease of the hardness of the mild phase or with increase of volume fraction of the mild phase[3]. Therefore, the orders of stretchability of these types are Type FM>Type B_I>Type B_{II} with a fixed strength level. On the other hand, it has been confirmed that the stretch-flangeability of complex-phase steel can be improved with decrease of the hardness ratio[3]. In this case, the orders of stretch-flangeability of these types are Type B II > Type B I > Type FM.

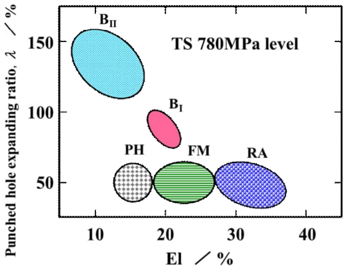

Figure 8. Relationship between elongation and punched hole expanding ratio in 780MPa level hot-rolled steel sheets

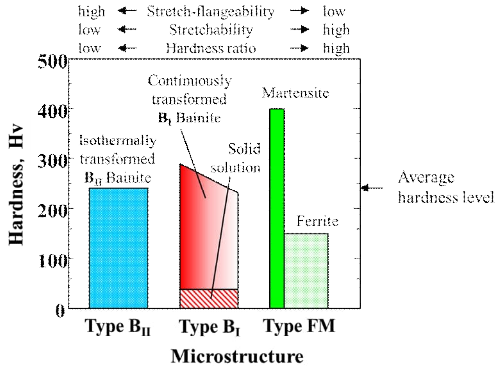

Figure 9. Schematic illustration of the hardness of component phases of Type B II, Type B I and Type PM

4. Conclusion

In order to apply the hot-rolled high-strength steel sheets to the suspension parts with aim of reducing the automotive weight, the effects of microstructures and additional elements on formability were investigated. The fine Type B_I strengthened by solid solution is the best material for the case that is required both stretchability and stretch-flangeability at the range of tensile strength 590 to 780MPa level. The superiority of Type B_I to Type FM and Type RA in stretch-flangeability is caused by the lower hardness ratio of the hard phase to the mild phase. On the other hand, the superiority of Type B_I to Type B_{II} in stretchability is caused by the lower hardness of the mild phase.

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