The Effect of Niobium and Molybdenum Co-Addition on Bending Property of Hot Stamping Steels

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In order to improve the bending property of higher strength grade hot stamping steel, the traditional manganese-boron steel should be modified by an adjustment of alloy elements, such as niobium, molybdenum…etc., to refine its grain and to eliminate its inclusions. In this study, the effects of niobium and molybdenum additions on the microstructure and the mechanical property of hot stamping steels have been investigated by using OM, SEM, TEM and VDA238-100 bending test. The results indicated that the bending energy of steel with niobium and molybdenum additions could be greatly improved due to its refined grain and the inhibition of crack origins, such as nitrides and sulphides, which are harmful to bending crack propagation. These analytic results are useful in developing ultra-high grade hot stamping steels in future.

Keywords: Hot stamping, Ultra-high strength steel, Bending test

1. INTRODUCTION

Along with the intensifying energy crisis and environmental problems, energy saving and safety have become the most important R&D issues for the steel and automobile industries. To achieve these goals, weight reduction is the most effective approach, which leads to the fast development and application of advanced high strength steels(1). However, in the forming process of high-strength and ultra-high strength steel sheet, there are problems such as big forming forces, serious spring back, possible fracture, and hard to form complex parts. Today, a novel technology that uses quenchable steel sheet to carry out hot stamping is considered as a solution in overcoming the above- mentioned difficulties.

Hot stamping steel is a new type of ultra-high strength steel used for automotive parts, such as B-pillar, A-pillar and door beam, etc.(2,3). In the event for side impact, automotive parts like the B-pillar often experience a sharp bending or buckling deformation. Therefore, specific tests have been designed to evaluate the bending angle which leads to cracking. European OEMs require hot stamping steel to fit in with a minimum bending angle of between 60 and 70 degrees in a three-point-bending test according to VDA238-100(4). However, it was found that premature cracking often occurs when a bending process begins. In order to improve the bending performance, a proper tempering treatment after hot stamping was sometimes considered. It is similar to the treatment of Q&T steels. Substantial research on tempering hot stamped components revealed that both toughness and bending angle could be improved to some extent. However, tempering treatment compromised the maximum bending force by 24% due to a decrease of tensile strength from 1500 to 1020MPa. An additional problem is the so-called tempering embrittlement in the temperature range below 600℃ which causes a decrease in total elongation as well as a loss in strength. Last but not least, a tempering treatment, if applicable, must be integrated into the hot stamping line and would increase the cost for the hot stamped automotive parts. Due to these reasons, Volkswagen appealed the new alloying concept for hot stamping steels. It should be developed having the same strength level but inherently performing better toughness and bendability without additional treatments(5).

In this study, a new hot stamping steel with a higher strength as well as a good bending performance was developed. Especially, the effects of niobium and molybdenum alloying additions on the microstructure and the related mechanical properties of the hot stamping steel were discussed. By a microstructure observation and a fractographic analysis, the concept by Volkswagen was executed and a mechanism of improving the bending property for hot stamping steels was proposed.

2. EXPERIMENTAL METHOD

Four steel alloys were designed in this study. Two were 0.3%C Manganese-Boron steels, termed as 30A and 30B. The 30B was added with niobium. The other two were 0.35% C manganese steels without any boron addition, labeled as 35A and 35B. The 35B was added with niobium and molybdenum (Table 1).

Table 1 Chemical composition of the steels in this study (in wt%)

Steel	C	Si+Mn+Cr	B	Nb	Mo
30A	0.3	1.2~1.6	≦0.005	--	--
30B	0.3	1.2~1.6	≦0.005	≦0.04	--
35A	0.35	1.2~1.6	--	--	--
35B	0.35	1.2~1.6	--	≦0.04	≦0.2

Figure 1 shows the entire experimental procedure, including alloy preparations, various rolling and annealing treatments, and final evaluation and analysis. First of all, these four steel alloys were melted in a vacuum induction melting furnace (VIM) and were cast into flat ingots respectively. Then these ingots were hot rolled, cold rolled and annealed into raw steel sheets with a gauge of 1.5mm. Finally, the raw steel sheets were evaluated by a hot stamping simulation at 930℃, a tensile test, a microstructure analysis with OM/SEM/X-ray and finally a three-point bending test in accordance with VDA238-100[4] (Fig.2).

3. RESULTS AND DISCUSSION

3.1 Mechanical property & microstructure of raw steel sheet

The results of the OM observation revealed that the matrixes of the four as-hot-rolled alloys mainly consisted of the ferrite, pearlite and bainite phases, as shown in Fig.3. The tensile strength is in the range of 600MPa for 30A and 30B alloys, and is of 700MPa for 35A and 35B alloys. After a cold rolling and annealing at 800℃, the matrixes of the four alloys mainly comprised of the ferrite, pearlite and carbides phases, as shown in Fig.4. It is apparent that the matrix of the alloy exhibits a finer microstructure when adding niobium and molybdenum, such as 30B and 35B alloys.

3.2 Mechanical property & microstructure of hot stamped alloys

The results of tensile properties of the four cold-rolled annealed sheets after hot stamping at 930℃ indicate that the tensile strength of 0.30%C alloys reaches a level of 1700MPa and that of 0.35%C alloys are even higher than 1900MPa. It is suggested that a higher strength of hot stamped alloy can be achieved by a higher alloy addition, such as carbon, boron, niobium and molybdenum. However, there is no apparent difference in its elongation (Fig.5). In addition, the hot stamped tensile strength trend for these four alloys and 22MnB5 steels was also arranged in Fig.6. The result shows that the tensile strength raises linearly as the carbon content increases and the linear regression formula is TS(MPa) = 3901.8 x [wt%C] + 619.71. Therefore, the hot stamped tensile strength can easily be designed by adding the corresponding carbon content.

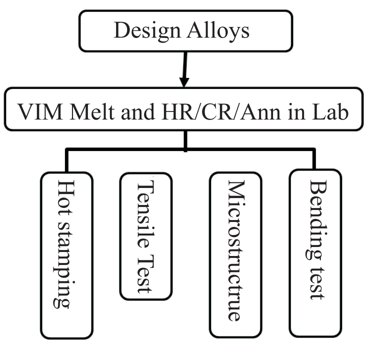
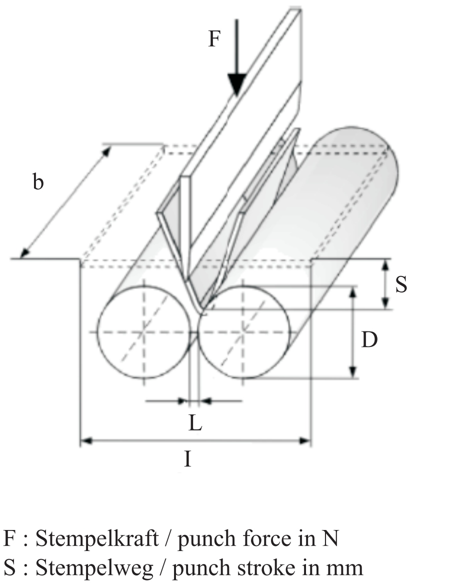


Fig.1. Schematic representation showing the experimental procedure.



F : Stempelkraft / punch force in N
S : Stempelweg / punch stroke in mm
D: Rollendurchmesser / roller diameter in mm
L: Rollenabstand / roller distance in mm
I : Probenlange / sample length in mm
a : Probendicke / thickness in mm
b : Probenbreite /sample width in mm
r : Stempelradius / punch radius in mm
α : Biegewinkel / bending angle in

Fig.2. Schematic illustration of the three-point bending test according to VDA238-100.[4]

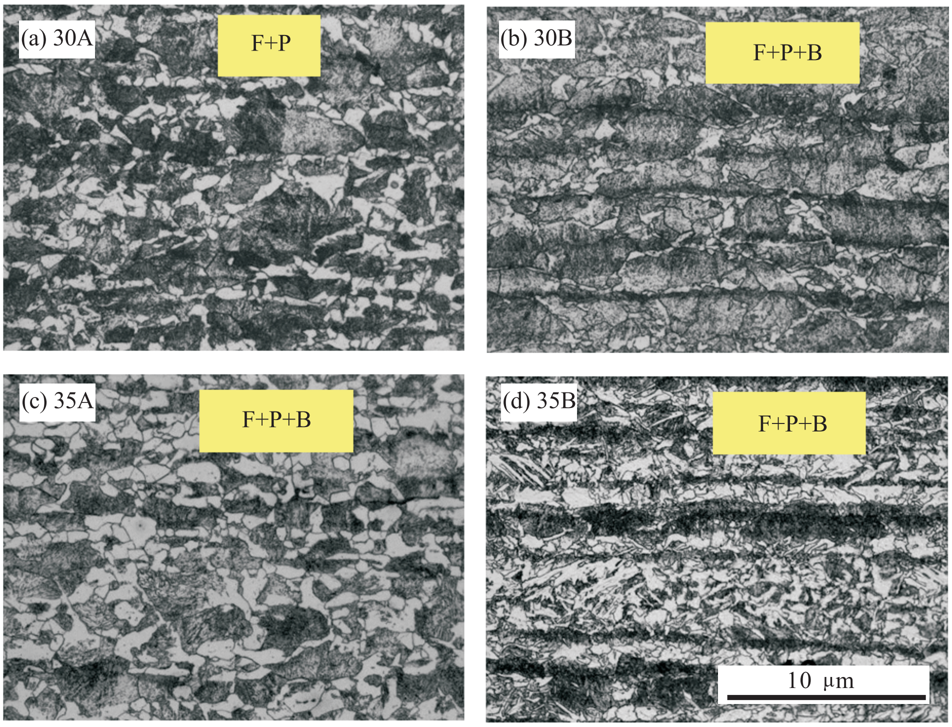


Fig.3. Optical microstructures of hot rolled steel alloys, (a) 30A, (b) 30B, (c) 35A and (d) 35B.

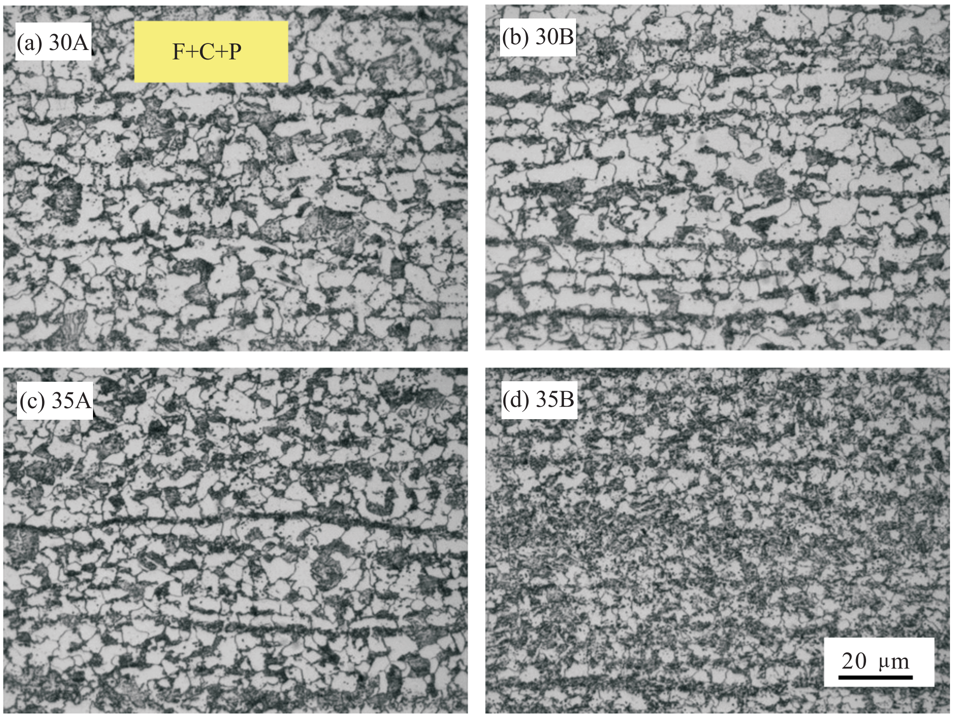


Fig.4. Optical microstructures of cold rolled annealed steel sheets, (a) 30A, (b) 30B, (c) 35A and (d) 35B.

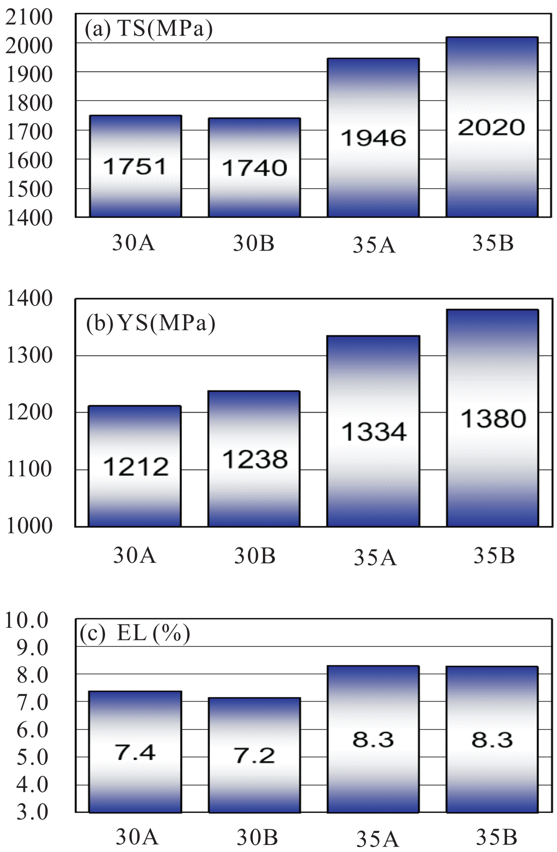


Fig.5. Tensile properties of cold-rolled annealed sheets after hot stamping at 930℃, (a) TS, (b) YS and (c) EL.

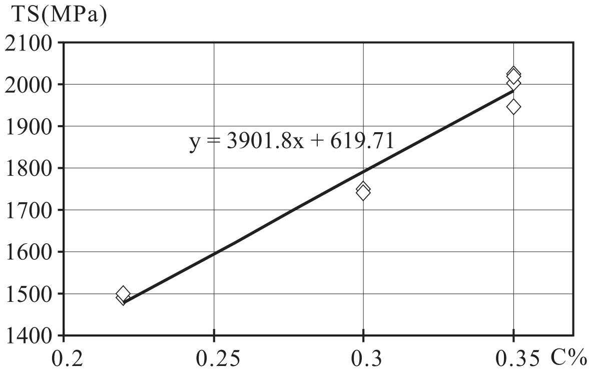


Fig.6. Tensile strength trend for 0.22~0.35%C MnB steels after hot stamping at 930℃.

Furthermore, the microstructure of hot stamped specimens was observed by SEM and X-ray, as shown in Figs.7 and 8. These results reveal that these hot stamped alloy sheets exhibited an all martensitic microstructure without any retained austenite phase. It means that all alloys have sufficient hardenability for the hot stamping procedure at 930℃, even 0.35%C alloys without any boron addition. Moreover, the addition of niobium and molybdenum can apparently refine the grain size for 30B and 35B alloys, compared to 30A and 35A respectively (Fig.9).

3.3 Bending property of hot stamping alloy sheet

In order to investigate the effect of the addition of niobium and molybdenum on the bending property of

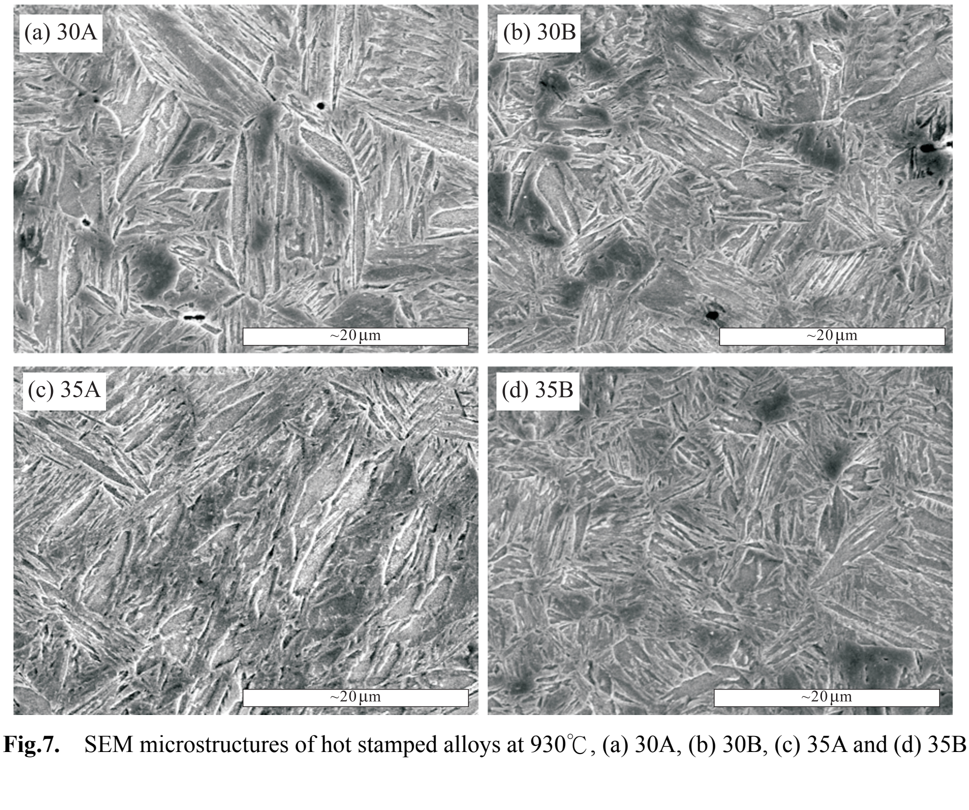


Fig.7. SEM microstructures of hot stamped alloys at 930℃, (a) 30A, (b) 30B, (c) 35A and (d) 35B.

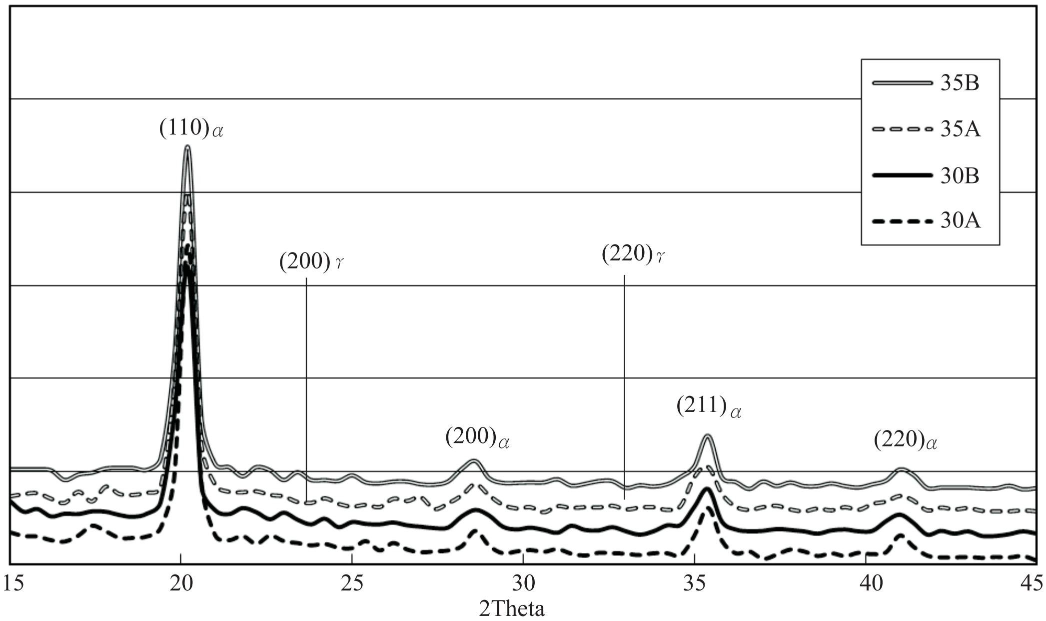


Fig.8. X-ray analysis of the four hot stamped alloys at 930℃.

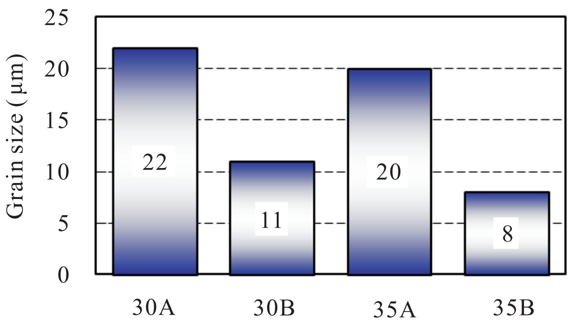


Fig.9. Grain size analysis of the four hot stamped alloys at 930℃.

hot stamping steels, the four alloy sheets were evaluated by a three point bending test in accordance with VDA238-100 after being hot stamped at 930℃. The results show that the addition of niobium in 0.3%C alloys, which have strength levels of 1700MPa, didn't improve the bending property by much. However, the addition of niobium and molybdenum in 35%C alloys, which have strength levels of 1900MPa, greatly improved its bending performance. It is worth mentioning that the bending angle of 35B alloy can meet the European OEMs requirement, with bending angle of between 60 to 70 degrees, and the bending energy of that is even more superior to that of 22MnB5, which strength levels of 1500MPa, as shown in Fig.10.

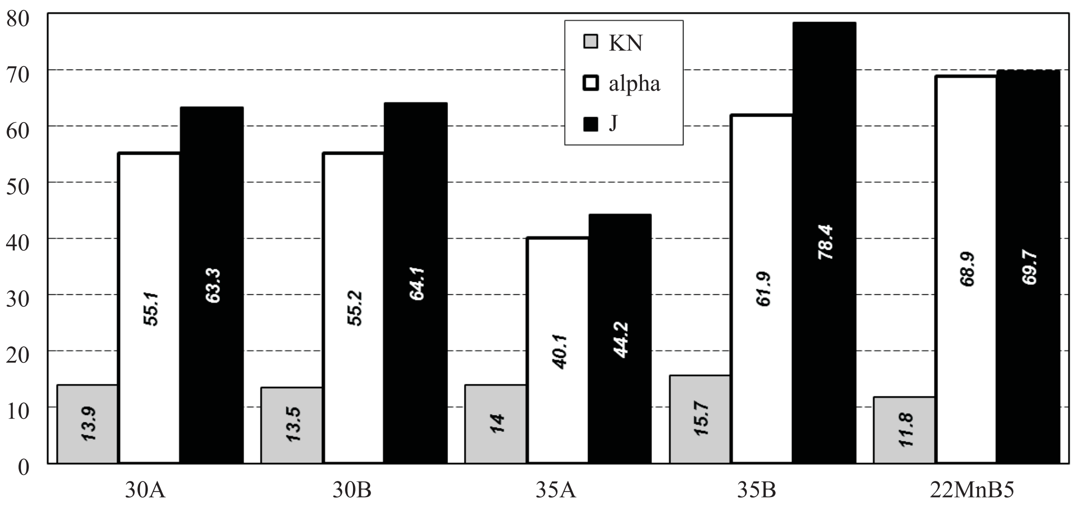


Fig.10. Bending properties of hot stamped alloys at 930℃.

Furthermore, the cracking in the bending surface of 35% C alloys was observed and analyzed by SEM and EDS, as shown in Fig.11. The results of fracture morphology show that there are substantial slim MnS and granulated TiN inclusions on the fracture surface of 35A alloy, but only slim MnS inclusions on that of 35B alloy. It is because of the titanium element, which enables the hardenability effect of boron(6), was removed from 35B alloy. In addition, it had been verified in our previous study that leveling down the sulfur content could also eliminate the sulfide inclusions in the 22MnB5, to enhance its bending performance.

3.4 Mechanism of improving bending property of hot stamping steel

Figure 12 is the schematic illustration of the mechanism of improving the bending performance of hot stamping steel. With the addition of niobium and

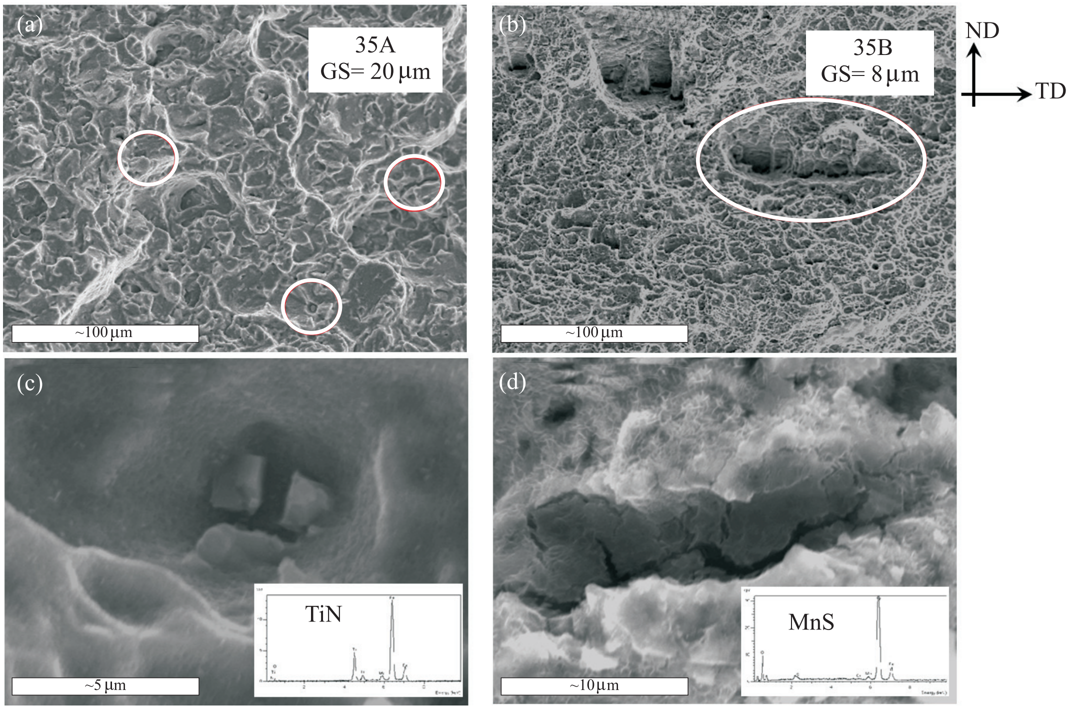


Fig.11. Fracture morphology of hot stamped steels after the bending test, (a) 35A, (b) 35B, (c) EDS analysis of TiN, (d) EDS analysis of MnS.

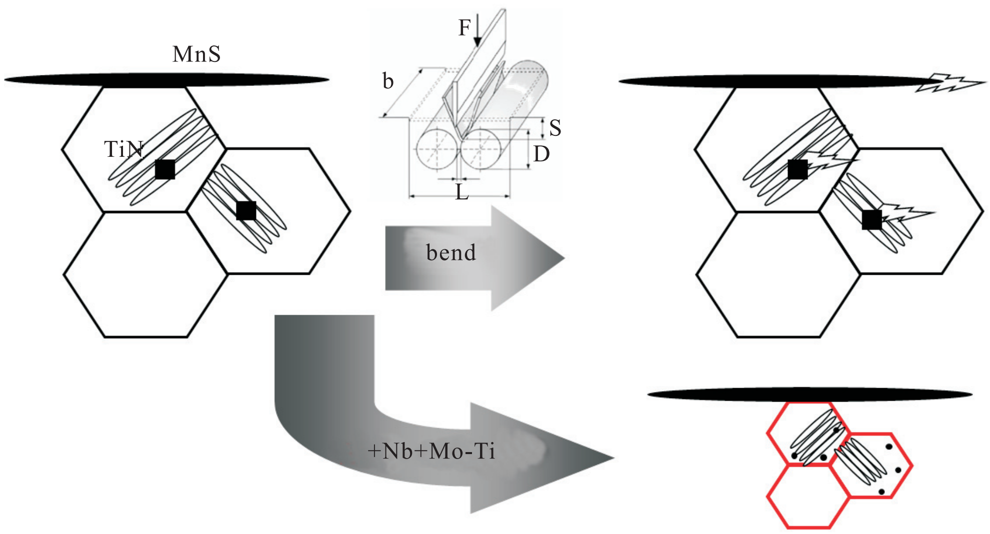


Fig.12. Schematic illustration of the mechanism of improving bending property.

molybdenum in steel alloys, the grain size can be refined to increase the amount of high-angle boundary which blocks the propagation of premature bending cracks. In addition, removing or leveling down the alloying content of titanium and sulphur can reduce the amount of TiN and MnS inclusions, which are potential crack initiations. Thus, it has been demonstrated in this study that the bending performance, such as bending angle and energy, can be improved by grain refinement and the elimination of inclusions, even for the higher strength grade hot stamping steel.

4. CONCLUSIONS

1. After hot stamping at 930℃ for cold rolled annealed steel sheets, 0.3%C alloys reach the level of 1700MPa and 0.35%C alloys reach the level of 1900MPa. The microstructure of all the samples are in a fully martensite phase without any retained austenite.
2. Co-addition of Nb or Nb/Mo can refine the primary austenite grain size to increase the amount of high-angle boundary. Removing and leveling down the amount of Ti and S content can decrease the number of crack sources, such as TiN and MnS. These are beneficial in raising the bending angle and energy.
3. These analytic results are useful in developing ultra-high graded hot stamping steels in future.

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