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Author(s)	Zhang, Yansong; Shen, Jie; Hu, Xiaozhou
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Effect of Tempering Parameters on Microstructure and Mechanical Properties in Resistance Spot Welding of Advanced High Strength Steels

Yansong ZHANG*, Jie SHEN* and Xiaozhou HU*
*** Shanghai Key Lab of Digital Auto-body Engineering, Shanghai Jiao Tong University, Shanghai and 200240, P.R.China**

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1. Introduction

The demands for lightweight bodies and high safety requirements have promoted the widespread use of Advanced High-Strength Steels (AHSS) in car body manufacturing. One of the most commonly used groups of AHSS in automotive industry are dual phase (DP) steel, which is a kind of material used in automobile production to realize automobiles' weight reduction without decrease strength and stiffness. Therefore, the traditional low carbon and low alloy steel used in automobile industry are gradually replaced by high strength steels such as DP [1-2].

Resistance spot welding (RSW) is the dominant joining method in car body assembly due to its low cost, high efficiency and easy automation. However, the microstructure of DP will cause asymmetric cooling speed and result in crack and shrinkage voids during resistance spot welding process. The strength of nugget will lower than base material and interfacial fracture failure mode will appear during mechanical test. This failure mode will reduce the cross tension strength by 10% and low cycle fatigue strength by 25%. As a result, optimizing welding process parameters to avoid the interfacial fracture mode of DP are becoming more and more important [3-5].

2. Experimental procedure

In this investigation, the resistance spot welding of multiple stacks of steel sheets was used as an example to evaluating the effect of tempering parameters on microstructure and mechanical properties. 0.8 mm thick hot-dipped galvanized (HDG) low carbon steel SAE1004, 1.4mm thick (HDG) DP600 and 1.8mm thick (HDG) DP780 steels were used in this study. All have the coating thickness of 60 gram/m2. The chemical composition of these steels are measured and listed in Table 1.

Table 1 Chemical composition of various steels

Steel	Chemical composition (%)					
	C	Mn	P	S	Si	Al
SAE1004	0.037	0.21	0.01	0.02	0.018	0.04
DP600	0.08	1.74	0.012	0.003	0.016	0.041
DP780	0.15	1.80	0.004	0.016	0.010	0.048

The RSW process is realized by use of a servo gun welding system having a medium frequency direct current (MFDC) welder. The servo gun can precisely control the welding force of the electrode to guarantee the steady contact. The advantage of the MFDC technology is to enable a very fast reaction of weld current with respect to any variation in the RSW process.

In this study, the multiple stacks of three sheets is composed of 0.8 mm thick SAE1004 as top sheet, 1.4 mm thick DP600 as middle sheet and 1.8 mm thick DP780 as bottom sheet. Class II copper alloy with chromium and zirconium electrode is used in the experiment. The adopted tempering parameters and welding process parameters are listed in Table 2.

Table 2 Welding parameters and tempering parameters

Welding current: 9.1kA; electrode force: 5.5KN Welding time:360ms; holding time: 920ms		
Number	Tempering current/kA	Tempering time /ms
0	0	0
1	4.7	800
2	5.8	800
3	6.8	800
4	4.7	1600
5	5.8	1600
6	6.8	1600
7	4.7	2000
8	5.8	2000
9	6.8	2000

Weld Characterization can be measured from the micrographs of the joint cross section, which is prepared by using Nital 4% etch applied after mechanical grinding and polishing. After the metallographic test, the Vickers hardness tests were conducted using a 200 g load and hold time of 10 sec. Five replicates were prepared for the metallographic and hardness tests.

3. Result and Discussion

DP steels consist of a ferritic matrix containing a hard martensitic second phase in the form of islands. Increasing the volume fraction of hard second phases generally increases the strength. DP (ferrite plus martensite) steels are produced by controlled cooling from the austenite phase (in hot-rolled products) or from the two-phase ferrite plus austenite phase (for continuously annealed cold-rolled and hot-dip coated products) to transform some austenite to ferrite before a rapid cooling transforms the remaining austenite to martensite. Figure 1 shows the cross section of weld nugget with different tempering current and time [6]. Figure 2 shows the comparative results of the SEM micrographs with and without tempering. From these

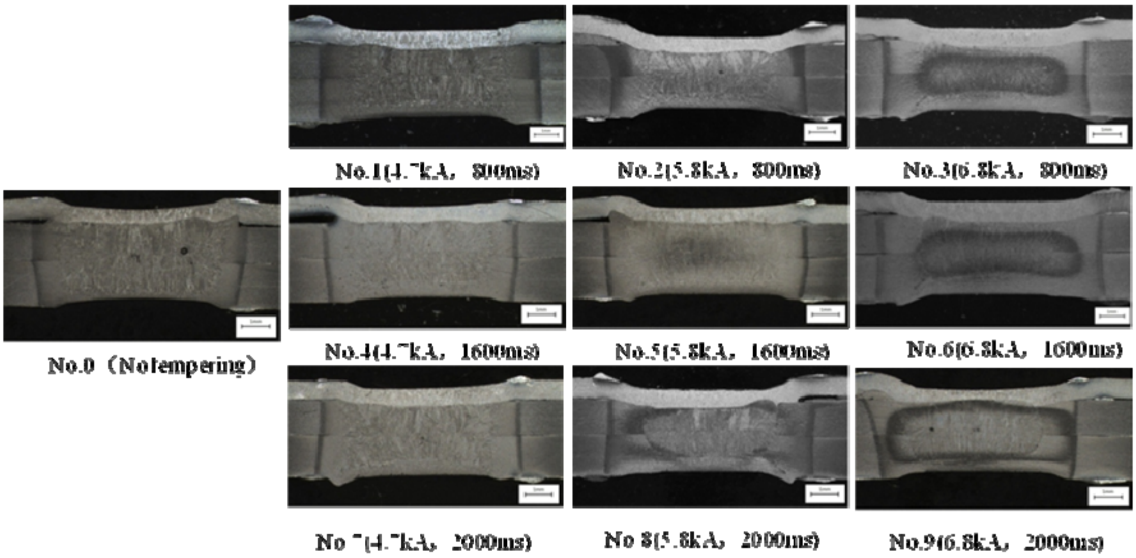

Fig. 1 The cross section of weld nugget with different tempering parameters

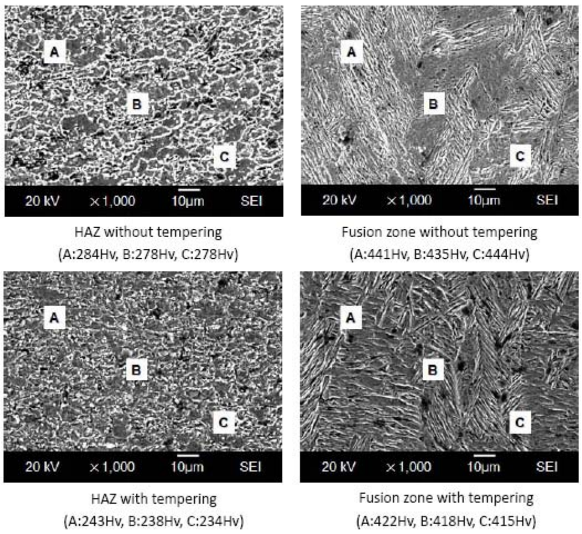

Fig. 2 SEM micrographs of the spot weld regions

pictures, it is significantly showed that the tempering had the obvious soft effect on the microstructure of nugget regions. The microstructure of the tempering sample is more tiny and dense than that of the without tempering sample. But with the increase of tempering current and time, there is a black circle in the middle of the weld nugget. This showed that the selection of the tempering parameters is important to the weld nugget of AHSS.

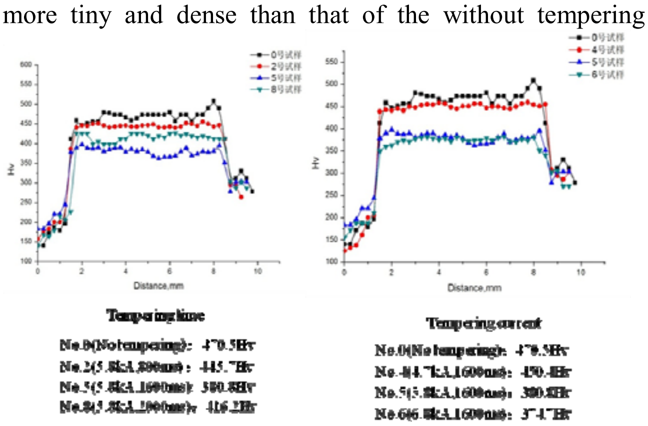

Fig.3 Microhardness profile of spot weld under different tempering parameters

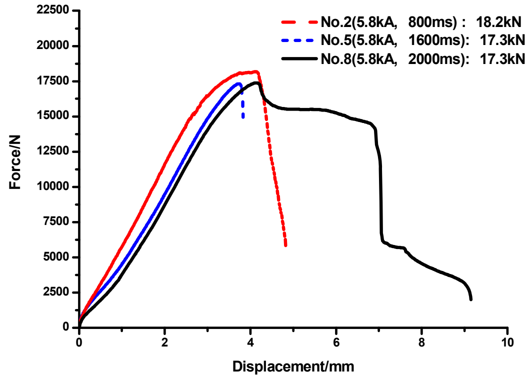

Fig.4(a) tempering time

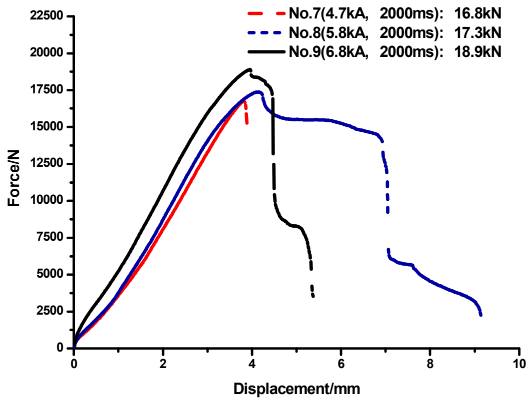

Fig.4(b) tempering current

Fig.4 Force-displacement curve of spot weld under different tempering parameters

Figure 3 shows the microhardness profile of spot weld under the different tempering parameters. when the temper time or temper current increases, the average hardness of nugget decreases. But under high temper level, the average hardness increases against the rules. The reason maybe is that under the full temper condition, the temperature of nugget is as high as the temperature of nugget recrystallization. This may be meaningless for tempering treatment in resistance spot welding. Figure 4 shows the force-displacement curve of spot weld under different tempering parameters. It can be seen that there is almost no difference in maximum force when different tempering parameters are used.

Base on the above analysis, the temper process would influence the microstructure and mechanical properties of the weld nugget. To determine the tempering treatment in resistance spot welding, an orthogonal test is used to find the optimal parameter combination. In the confirmatory experiment of tempering process, the weld current was chosen of the lower boundary of the weld lobe. So, the weld current is changing from 9.1 kA to 9.7kA, and the weld time is still 360ms. The orthogonal test has three factors: cooling time, temper current and temper time. Each factor has four levels. The cooling time is 200ms, 400ms, 600ms, and 800ms. The weld current is 4kA, 5kA, 6kA, 7kA. The weld time is 400ms, 800ms, 1200ms, 1600ms. The detailed information is shown in table 3.

Table 3 Factor and level of DOE

Parameter: Current 9.7Ka, Welding time:360ms			
Level	A(Cooling time)/ms	B(Tempering current)/kA	C(Tempering time)/ms
1	200	4	400
2	400	5	800
3	600	6	1200
4	800	7	1600

With all the 16 groups of samples welded based on DOE, the metallographic experiment, microhardness measurement, tensile shear test are needed to test the microstructure and mechanical properties of spot weld. For each optimization goal, the results shows that the cooling time is the most important factor with regard to the nugget diameter and the average hardness, and the tempering time is the most important factor with regard to the maximum tensile shear force and the maximum displacement. The range analysis is easy to get the parameter optimization combination. The conclusions of range analysis and variance analysis for each factor are the same.

Based on the analysis results of DOE, the optimal parameter combination of tempering treatment in resistance spot welding is cooling time 600ms, temper current 6kA, and temper time 400ms.Through an experiment to measure the quality of the best parameter combination sample, the average hardness of weld nugget is 416.2 Hv, Compared with 470.5 Hv without tempering, the average hardness decreases by 11.5%, the maximum tensile shear force decreases by 0.5%, which is negligible, and the fracture mode is button fracture, which is shown in fig5.

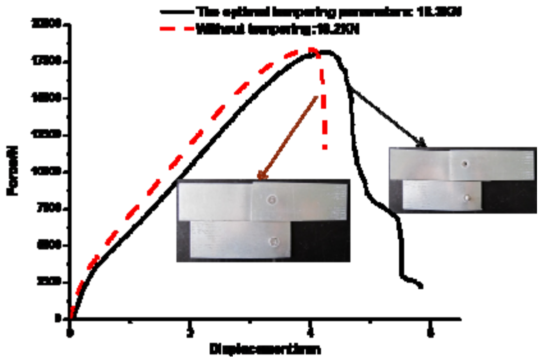

Fig.5 Comparison results considering tempering

4. Conclusions

With the increase of the temper time or temper current, the microstructure will become more tiny and fine. Correspondingly, the average hardness of fusion zone will decrease. The fracture mode of tensile-shear joint will change from interfacial fracture to button fracture. For 0.8mm SAE1004, 1.4mm DP600 and 1.8mmDP780 three-layer steel sheets, the best parameter combination of the tempering treatment in resistance spot welding is cooling time 600ms, temper current 6kA, and temper time 400ms. The average hardness of weld nugget decreases by 11.5%, the maximum tensile shear force decreases by 0.5%, and the fracture mode is button fracture.

Acknowledgements

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