Microstructure of resistance spot weld ultra high strength steel Q&P980

Tao Liu¹, Hua Wang¹, Haifeng Yang²*, Chongjian Ke³, Li Zhou³, Hongyun Zhao³

¹School of Automotive Engineering, Harbin Institute of Technology at Weihai University, Weihai, China
²Shandong Provincial Key Laboratory of Special Welding Technology, Harbin Institute of Technology at Weihai, Weihai, China
³Baosteel Iron & Steel Co, Ltd, Shanghai, China

*Corresponding author e-mail: yanghaifeng10@163.com

Abstract. 1mm thick Q&P980 steel plate was resistance spot welded and the appearance and microstructure of welded joint were investigated. The results show that Q&P980 steel achieves a better connection. When welding current is 12.5 kA, welding time is 10 cycle, and electrode pressure is 2.4 kN. The joint can be divided into Fusion Zone (FZ), Coarse Grained (CG) HAZ, Fine Grained (FG) HAZ, and Inter Critical (IC) HAZ, Base Material (BM). The FZ undergoes recrystallization, and the HAZ undergoes a phase change due to thermal cycling and plastic deformation. FZ, CGHAZ and FGHAZ are completely austenitized and lath martensite is formed. ICHAZ generates tempered martensite.

1. Introduction

With the rapid development of the automotive industry, environmental protection and energy issues are becoming more and more serious, and automotive lightweight has become an important development trend in the automotive industry. Advanced high-strength steel, aluminum alloy, magnesium alloy, composite materials and other new materials are continuously applied to automobiles[1-3]. As the third generation of advanced ultra-high strength steel, Q&P980 has the advantages of low alloying element content, good mechanical properties and low cost. It can achieve the purpose of reducing the quality of the whole vehicle while ensuring the safety performance of the automobile. It is suitable for automobile body structural parts and internal reinforcing plates, and has broad application prospects[4-5].

At present, resistance spot welding is still widely used in automobile bodies. The mechanical properties of automotive steel spot welded joints determine the safety performance of automobiles[6-7]. Therefore, the microstructure and performance research of ultra-high-strength steel resistance spot welded joints have attracted the interest of many experts and scholars. LIU et al. conducted a double-pulse resistance spot welding study on Q&P980. Among them, partial melting zone became a crack sensitive zone due to segregation of P element, and liquefied grain boundary, liquefaction crack and softening were found in this zone. The liquefaction crack accelerated the crack propagation of fatigue failure[8]. EFTEKHARIMILANI et al. performed double-pulse resistance spot welding on Q&P980, and the second nugget under double pulse was completely martensitic. The annealing zone was equiaxed martensite, and the element segregation was significantly reduced. Double-pulse spot welding could...
improve the mechanical properties of the joints and achieve good failure mode[9]. FAN et al. carried out the laminar fracture experiment on Q&P980 steel spot welded joints under plane tension pulse with an air gun. The change rule of microstructures during laminar fracture was obtained. It was found that the spallation strength of welded joints with defects in the nugget center was less than the prescribed spallation strength or dynamic bearing capacity[10].

In this paper, the joint forming, microstructure of Q&P980 steel resistance spot welded joints are studied, which provides a theoretical reference for the application of Q&P980 steel on the body structure.

2. Experiment materials and method

The experiment material is 1mm thick Q&P980 steel plate, and its chemical composition and mechanical properties are shown in Tables 1 and 2, respectively. At room temperature, the microstructure of the base metal is a ferrite matrix, a carbon-poor lath martensite matrix, and a small amount of carbon-rich retained austenite, as shown in Figure 1. The size of the experiment piece is 150mm×40mm, and the weldment overlap size is 40mm, as shown in Figure 2. The spot welded equipment is an DN-50 AC spot welder with a current output frequency of 50 Hz. Double-sided single-point welding is performed using a spherical planar electrode with a face diameter of 6 mm, and the electrode material is Cr-Zr-Cu.

| Table 1. Chemical composition of Q&P980 steel (mass fraction,%). |
|-------------------|------------------|-----------------|----------------|-----------------|-----------------|
| Mn | Si | C | Al | P | Ti |
| 1.876 | 1.386 | 0.201 | 0.036 | 0.008 | 0.006 |

| Table 2. Mechanical properties of Q&P 980 base metal. |
|-------------------|------------------|------------------|-----------------|-----------------|
| σs/MPa | σb/MPa | Elongation to fracture /% | Hardness |
| 742 | 1129 | 20.7 - 25.3 | 330 |

Figure 1. Microstructure of Q&P980 Steel.

Figure 2. Sample size of tension-shear test.
The joint is cut from the joint by wire cutting, mounted, polished, polished, etched with 5% nitric acid solution. The diameter of the joint is measured by DSX510 optical digital microscope. The macroscopic morphology and microstructure of the joint is observed. When stretching, 1mm steel plate should be added at both ends to eliminate the additional torque generated during direct clamping. The HMAS-D1000SZ microhardness measurement system was used to measure the Vickers hardness of the spot weld joint, the load was 300g, and the load was maintained for 10s. The distance between the points in the nugget zone is 0.4mm, and the distance between the heat affected zone and the base material zone is 0.2mm.

3. Experimental results and analysis

3.1. Appearance analysis of spot welded joints

Fig. 3 is the spot welded joint in which the welding current \( I = 12.5 \) kA, the welding time \( t = 10 \) cycle, and the electrode pressure \( F = 2.4 \) kN. The appearance of spot welded specimens has no external spatter, no electrode adhesion, regular plastic ring, no distortion of welded joints and good solder joint formation, as shown in Figure 3a. The joints can be divided into Fusion Zone (FZ), Coarse Grained (CG) HAZ, Fine Grained (FG) HAZ, and Inter Critical (IC) HAZ, Base Material (BM), as shown in Figure 3b. The joint has a uniform microstructure, no shrinkage holes, cracks, slight spatter, and good welded quality. The weld joint diameter is 7.69 mm, the indentation is 0.35 mm and the penetration rate is 66.2%. All of them meet the requirements of spot welded dimension for automotive steel plate.

3.2. Microstructure analysis of spot welded joint

Figure 4 shows the microstructure of the Q&P steel spot welded joint. Typical recrystallization occurs in the FZ, and its microstructure is coarse lath martensite, as shown in Fig. 4a. During the welding process, the liquid metal firstly undergoes typical twinning crystallization at the semi-melted grains. Austenite precipitates along the fusion line, continues to grow in the direction of action of the electrode and stops growing after contact with the center. The columnar martensite is formed by water cooling inside the electrode, and has obvious directionality.

HAZ undergoes a phase transformation due to thermal cycling and electrode pressure. During the welding process, CGHAZ and FGHAZ are completely austenitized, and the CGHAZ is affected by high temperature for a long time, and the microstructure is completely austenitized, which is close to the nugget zone. Conducive to the diffusion of carbon and the growth of austenite. After water cooling, a large amount of coarse lath martensite is formed. The thickness of the microstructure is between the nugget zone and the fine grain zone, which is slightly larger than the fine grain zone, as shown in Fig. 4b and Fig. 4c. The microstructure of ICHAZ is lath martensite, ferrite, a small amount of tempered martensite and retained austenite. The temperature in this area is low and the heat cycle time is short, and the microstructure is partially austenitized, which is not conducive to the growth of austenite. After cooling by water, austenite transforms into fine lath martensite, Tempering of martensite in low temperature environment produces finer tempered martensite. At the same time, under the action of the
electrode pressure, the retained austenite undergoes partial phase transformation to form fine lath martensite. Compared with BM, the lath martensite is finer but the content is increased, and the ferrite is also significantly less, as shown in Fig. 4d.

Figure 4. The microstructure with $I = 12.5 \, \text{kA}$, $t = 10 \, \text{cycle}$, $P = 0.3 \, \text{MPa}$. (a) FZ; (b) CGHAZ; (c) FGHAZ; (d) ICHAZ.

4. Conclusion
This paper have investigated the appearance and microstructure of Q&P980 spot weld joint. Based on the analysis and discussion above, the following conclusions can be drawn:

1. The appearance of the spot welded joint under welding current 12.5kA, welding time 10 cycle, electrode pressure 2.4kN is well formed. The weld joint diameter is 7.69 mm, the indentation is 0.35 mm and the penetration rate is 66.2%. Weld joint quality is qualified.

2. The FZ undergoes recrystallization, and the HAZ undergoes a phase change due to thermal cycling and plastic deformation. The FZ microstructure of the resistance spot welded joint is a coarse lath martensite in a columnar crystal form, and the HAZ microstructure is fine lath martensite, a small amount of ferrite and tempered martensite, and the martensite is relatively small.

References
[1] Wang Cunyu, Yang Jie, Chang Ying, et al, Development trend and challenge of advanced high strength automobile steels, J. Iron and Steel. 54 (2019) 1-6.
[2] Taub Alan I, LUO, Alan A, Advanced lightweight materials and manufacturing processes for automotive applications, J. MRS Bulletin. 40 (2015) 1045-1054.
[3] Kah P, Pirinen M, Suoranta R, et al, Welding of Ultra High Strength Steels, J. Advanced Materials Research. 849 (2014) 357-365.
[4] Zhu Guoming, Kuang Yonglin, Zhu Shuai, et al, Study on Process Microstructure and Property of Ultra-high Strength QP Steel for Automobile, J. Journal of Mechanical Engineering. 53 (2017) 110-117.
[5] An Keyu, Liang Jiamin, Xing Feifan, et al, Research status of the 3rd generation advanced high strength steels for automobiles—Q&P steels, J. Heat treatment of metals. 2 (2019) 1-6.
[6] Akihiko N, Junya N, Akira I, et al. Spot Weldability in Automotive Ultra High Strength Steel Sheet[C]/ the 1st international conference on automobile steel & the 3rd international conference on high manganese steels. 2016.
[7] Ikeda Rinsei, Weld Joint property and Welding Technologies in Resistance Spot Welding of Ultra-High Strength Steel Sheets, J. Yosetsu Gakkai Shi/journal of the Japan Welding Society. 84 (2015) 441-446.
[8] LIU X D, XU Y B, MISRA R, et al, Mechanical Properties in Double Pulse Resistance Spot Welding of Q&P 980 Steel, J. Journal of Materials Processing Technology. 263 (2019) 186-197.
[9] Eftekharimilani P, Vander Aa E.M. Hermans M.J.M, et al. The microstructural evolution and elemental distribution of a 3rd generation 1 GPa advanced high strength steel during double pulse resistance spot welding, J. Weld World. 61 (2017) 691-701. 
[10] Fan Chunlei, Ma Bohan, Chen Danian, et al, Spall Strength of Resistance Spot Weld for QP Steel, J. Chin Phys Lett. 33 (2016): 1-5.