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Research Article

Microstructure properties of welded S420MC dual phase steel

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Abstract:

In this study, the weldability and microstructure properties of S420MC dual phase (DP) steel joints fabricated by the resistance spot welding method (RSW) were investigated. The microstructures of the welds were examined by SEM and optical microscopy. The results showed that the microstructure of the weld metal region completely transformed into the ferrite phase, and deep and wide cracks occurred in this region and heat-affected zone. It was concluded that the RSW method should not be recommended for welding DP steel.

1. Introduction

DP steels are a type of low-carbon, low-alloy, or unalloyed high-strength steel that contains 20–25% hard martensite in the form of islands within a ferrite matrix in their internal structure [1-3]. In these steels, which are generally produced with low carbon, in addition to ferrite and martensite, pearlite, bainite, and residual austenite may also be found in the structure [4,5]. Due to their high strength and elongation properties, these steels are used in the production of automobile parts that require high strength and forming [6]. For this reason, intensive studies have been carried out on these steels in recent years. A study conducted by Salamci and Kabakci [7] on these steels showed that while the yield and tensile strengths increased with the increasing martensite volume ratio, the elongation values decreased. Similarly, there are many studies directly related to tensile strength and the volume percentage of martensite [8-10]. On the other hand, it has been shown that mechanical properties depend not only on the volume percentage of martensite, but also on many process parameters such as soaking temperature, cooling rate prior to quenching, quench and temper annealing temperature [5,11].

In material technology, there are some methods used to join two identical or different parts in areas where continuity between parts is required. Among these methods, the most preferred method is welding [12]. The four most popular types of welding procedures are gas metal arc welding, gas tungsten arc welding, shielded metal arc welding, and flux cored arc welding [13-15]. An important point is that the weldability of materials and, if welded, weld quality must be examined by destructive tests to determine whether a satisfactory weld has been produced, such as quasi-static tensile testing and dynamic cycling testing [16]. Corresponding to this, Örenler [17] showed that the fracture occurs in the filler metal, and the hardness values are close to each other in the filler metal region in all parts and are much lower than the hardness of the main material (Armox 500T armor steel). In another study [18], the maximum hardness value of ASTM A131 steels welded by the plasma arc welding (PAW) method was determined to be 221 HV in the transition zone of the welded joints due to the formation of needle-like ferrite. In addition, Aytekin et al. [19] determined that the average tensile strength, yield strength, and elongation of welded joints of dissimilar AISI 316 and AISI 4140 steels welded with the electric arc method are 408 MPa, 639 MPa, and 34%, respectively, and the fracture zones are on the side of the AISI 316 base material.

The automotive industry requires high-volume sheet metal joining, and quality control is paramount for customer safety. The RSW is an important method in automobile manufacturing today, and a typical vehicle could need 3000–4000 spot welds [20]. Meanwhile, it should not be forgotten that the structural integrity of the vehicle is closely related to the strength of the RSWs. In this study, the weldability and microstructure of S420MC DP steel welded with RSW were investigated.

2. Materials and Method

In the present study, S420MC DP steels with a thickness of 2.2 mm and a surface area of 100x30 mm were used as the base metal. The chemical composition of S420MC DP steel is given in Table 1.

***Tablo 1**. The chemical composition of S420MC dual-phase steel*

C	Si	Mn	P	S	V	Ti	Al
≤0.18	≤0.60	≤2.0	≤0.030	≤0.025	≤0.2	≤0.15	≥0.010

Spot welding (or RSW) is a type of electric resistance welding used to weld sheet metal products in which metal surface points in contact with each other are joined by heat obtained from resistance to electric current. In this study, RSW was carried out on a 7 kA pneumatically operated single phase RSW machine. Truncated cone caps of 13 mm diameter and 8 mm tip diameter made from Resistance Welding Manufacturers Alliance (RMAW) Class II copper-chromium material were considered for the bottom and top electrodes. The electrode pressing force and the distance between points were 6 bar and 45 mm, respectively.

For microstructure, the samples were ground by using different grades (600 to 1000 grit) of abrasive papers, polished, and then etched with nitric acid inset for 4-5 sec. The microstructures of the etched samples were determined with a scanning electron microscope (SEM).

3. Results and Discussions

The microstructure of S420MC DP steel before welding is 70-90 % martensite (light contrast) and 10-30% ferrite (dark contrast), as can be seen in Fig. 1.

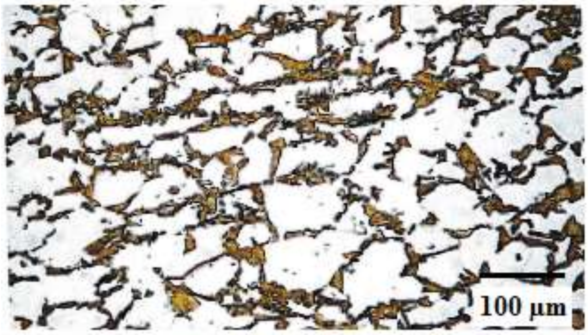

***Figure1.** Microstructure of S420MC DP steel before welding process*

Fig.2. SEM micrograph of S420MC DP steel welded with the RSW method. In this fig., weld regions such as base metal, heat-affected zone (HAZ), and weld metal are clearly visible.

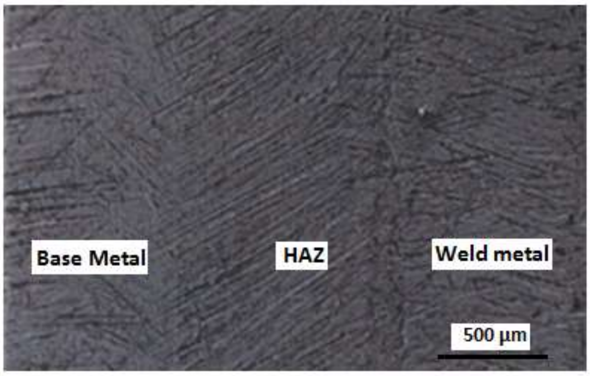

***Figure 2.** SEM micrograph of S420MC DP steel welded with RSW method.*

From Fig. 2, it can be seen that the microstructure of the weld metal region completely transforms into the ferrite phase due to a thermal effect exceeding the ferrite solvus temperature. Additionally, it is observed that grain coarsening occurs in this region, as in ferritic stainless steels. On the other hand, as we move from the weld metal to the base metal, the diffusion of carbon, oxygen, silicon, potassium, manganese, and iron transforms the ferrite-austenite balance in favor of ferrite due to the heat effect (Fig. 3).

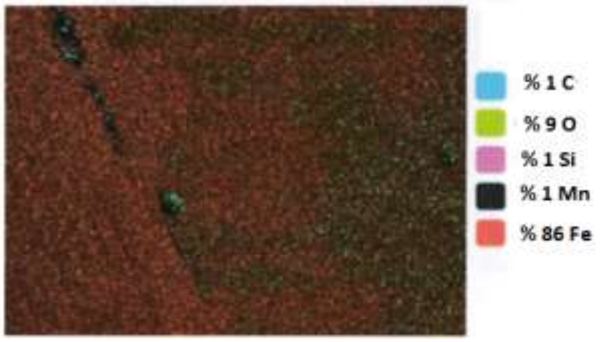

Figure 3. Chemical compositions of base metal region of S420MC DP steel welded with RSW

Fig. 4 shows that deep and wide cracks formed by the welding process are clearly visible in the welding area. We think that high residual stresses and a non-uniform temperature distribution cause some undesirable cracks to form in the weld metal and HAZ region. It is well known that cracks formed as a result of welding have important consequences for the welding process [21,22]. These not only reduce the strength of the weld due to a reduction in section thickness but can also easily propagate through stress concentration, especially under impact loading or during low-temperature use [23,24]. Thus, cracks in the weld are considered the most dangerous welding defect, and their presence is not allowed by general standards.

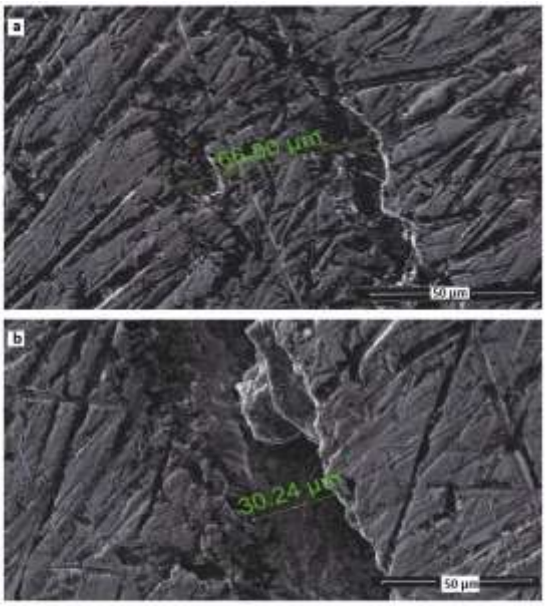

Figure 4. *The crack images obtained from weld metal (a) and HAZ region (b)*

In literature [25,26], it has been pointed out that the main reason for crack formation is that internal stresses exceed the strength of the weld and base metal. In addition, many problems, such as incorrect welding speed, inappropriate welding temperature, and incorrect bead shapes, are factors that cause crack formation. Studies also show a relationship between the welding technique used and crack formation [27]. Regarding this, it has been shown that techniques that minimize the amount of heat input, such as TIG welding or pulsed MIG welding, reduce the risk of crack formation [28,29]. On the other hand, the microstructure of the weld area is also effective against cracks. Corresponding to this, lee and Khang [30] showed that the acicular ferrite structure produced the greatest resistance to cold cracking due to the fine interlocking nature of the microstructure and high-angle grain boundary in HSLA (high strength low alloy) steels. Moreover, Huan-Li et al.[31] obtained a relationship between martensite structure and crack growth. He showed that the lower the recovery extent of the lath martensite structure and its lath width, the smaller the crack formation rate.

4. Conclusions

In this study, deep and wide cracks occurred in the weld area, which had a large amount of ferrite phase after welding. We think that the welding method used largely has an impact. To summarize, the RSW method is not a method that can be recommended for welding S420MC DP steels.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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