International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 01,January-2015

Comparison of Mechanical Properties and Weld Joint Strength of High Strength Low Alloy Steels with Low Carbon Steels

Shara Khursheed
Mechanical Engineering
Integral University, Lucknow

Sumita Chaturvedi
Mechanical Engineering
Integral University, Lucknow

Dr. K. M. Moeed
Mechanical Engineering
Integral University, Lucknow

Abstract-In automotive industry, the high strength steels have been used since many years but in recent years a new range of steels have been introduced known as high strength low alloy steels which can sustain high stresses more than 600N/mm and known as high strength low alloy steels. While the use of these steels lowers the overall weight of the vehicle its joint weldability and performance are the main area of concern. This paper deals with the Resistance welding of HSLA steels and modifications that are to be made in welding techniques and also compares HSLA steels with low carbon steels properties.

Keywords-HSLA steels, microstructure and mechanical properties, dual phase steels.

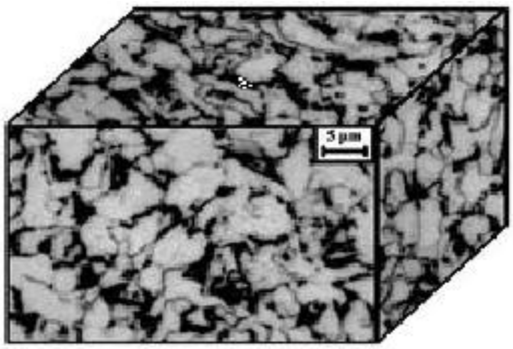

fig1 HSLA DP microstructure

1. INTRODUCTION-

Automotive companies are constantly seeking ways to improve the fuel efficiency of their vehicles and to build vehicles from materials that offer improved occupant safety. Any material intended for automotive use must be easily formable, weldable, coatable (for corrosion protection), and repairable. The use of resistance spot welding for forming lap joints have tend to manufacture of high strength steels within automobile industry. This provides automotive designers and manufacturers with the unique option of combining light weighting with the traditional steel advantage of low cost. The high energy absorption quality of HSLA steels make them suitable for fuel efficient also (Ref 1,2.). Although the technology of dual-phase steels is not new, and 590 MPa dual-phase steel has been available since 1979 (Ref.3), their uses in automotive applications prior to 2000 was virtually nonexistent. The table given below shows the various HSLA steels and their constituents along with the carbon equivalent factor.

Steel Grade	C	Mn	Mo	Cr	Si	CE
HSLA	0.060	0.640	0.010	0.030	0.240	0.139
DP600	0.100	1.523	0.196	0.197	0.157	0.326
DP780	2.082	0.181	0.012	0.239	0.036	0.427

Table1. Alloying Constituents of HSS

The strength is imparted to HSLA steels through grain refining, solution strengthening, transformation hardening and precipitation strengthening, Along with the high percentage of carbon and manganese they go through the process of heat treatment to increase their strength. The finished product has a duplex microstructure of ferrite with varying levels of martensite.

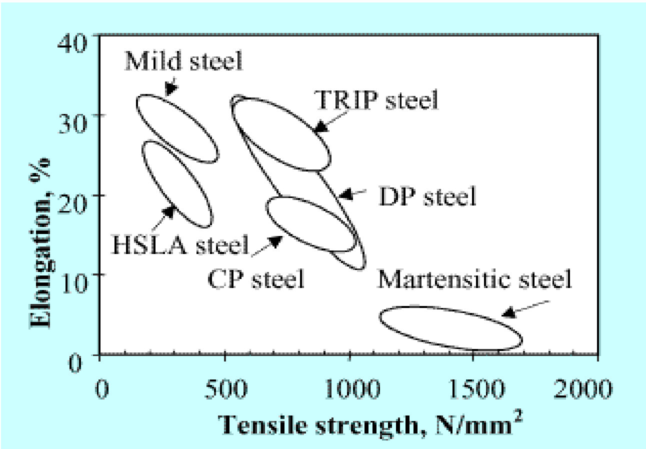

Fig2. Comparison of Tensile Strength and Elongation Of HSLA steels with other steels (Ref 4).

DP steel is a class of HS steel having a microstructure of soft ferrite and, depending on strength, between 20 and 70% volume fraction of hard phases, normally martensite. The soft ferrite phase is generally continuous, giving these steels good formability and ductility. When these steels are deformed, strain is concentrated in the lower strength ferrite phase, creating the unique high work hardening rate exhibited by these steels. DP steels are designed to provide a tensile strength up to 1000N/mm ^{2}.These steels can be hardened or strengthen through the hot or cold rolling depending in the conditions and the hardness level is controlled by the martensite amount as well as by heat treatment process. In martensitic steels, the austenite that exists during hot rolling is transformed almost entirely to martensite during fast cooling on the run-out table. Martensitic steels are based on a low carbon with several alloying element additions. Martensitic steels can provide very high strength (up to 1550N/mm ^{2}) and relatively good formability due to high strain hardening. Martensitic steels are often subjected to post-quench tempering to improve ductility, and can provide reasonable formability, even at extremely high strength. Typical candidate applications for martensitic steels are wheel discs, chassis parts and body reinforcements. These steels are applicable where high energy absorption capacity is needed such as wheels discs, chassis parts and body reinforcements.

2. RESISTANCE SPOT WELDING OF HIGH STRENGTH LOW ALLOY STEELS-

These steels are generally spot welded to get the required task and some of their characteristics are discussed below-

2.1. Heat Affected Zone Microstructure and hardening of Weld- Due to the greater hardness contents when HSLA steels are spot welded and than rapid cooled through electrodes a quenching effect occurs which produces a brittle martensite structure and due to this the weld can be very easily failed in tension test. (Ref 5, 6). Hence a reduced tensile strength and impact strength along of the lower weld joint can be seen. The hardness of HAZ and weld joint is generally depend on the parent metal composition. Higher carbon contents may lead to the cleavage fracture hence some of alloying elements are used which increases the hardness of HSLA steels such as manganese. The hardness profile of HS steel welds, which is related to the metallurgical characteristics of the steel and welding conditions used, can have a significant influence on the weld properties. Generally, a fully hardened weld and HAZ is obtained in HS steels having a tensile strength below 1000N/mm ^{2}. However, a fully hardened weld but softened HAZ is produced in HS steels with a tensile strength above 1000 N/mm $^{2.}$. The intercritical annealing or other heat treatments can also be done to obtain hardened dual phase steels.

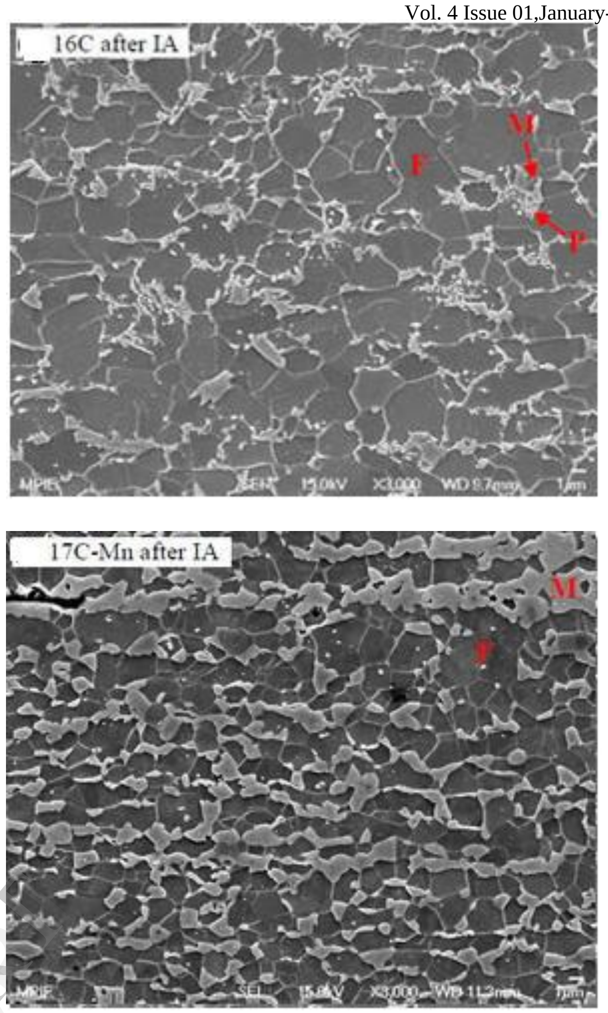

Fig3. Microstructure changes after intercritical annealing. (Ref 7).

2.2. WELDING OF HIGH STRENGTH LOW ALLOY STEELS-

Generally these steels are spot welded to obtain the best results but it differs in welding parameters and weld quality as compared to low carbon steels. To provide better corrosion resistance property dual phase steels are used with either galvannealed (zinc-iron alloy) or galvanized (pure zinc) coating. Due to their high electrical resistivity and expulsion susceptibility higher electrode higher electrode forces and lower welding currents are required. A 20 to 50% increased electrode force used for HSLA steels up to about 600N/mm ^{2} tensile strength compared to low carbon steels, but around 100% increase is suggested for the higher strength steels.

2.3 PARAMETERS OF RESISTANCE SPOT WELDING

A truncated class 2 electrode with 6.0mm face diameter was used as per AWS standards for sheet thickness ranges used in this study.(Ref.8) Cooling water flow rate and hold time also followed AWS recommendation of 4 L/min and 5 cycles, respectively. It should be noted that recommended practice of prompt electrode release (5 cycles after termination of weld current) is used here results in discontinuous cooling curves which can significantly increase the complexity of the steels' metallurgical response.

3. FRACTURE OF HIGH STRENGTH LOW ALLOY STEELS-

The strength of weld is defined through the tension test. The weld can be failed in three modes-

a) Full Button Fracture.
b) Interface fracture
c) Partial Interface Fracture.

Weld and heat-affected zone microstructures were examined to check for any imperfections such as pores and cracks and to provide an understanding of the tensile properties of the weld. Weld micro hardness profiles were determined by making hardness measurements at 0.4 mm spacing along a diagonal in a weld cross section. A interface fracture generally occurs in HSLA steels due to their hard and brittle microstructure. The maximum stresses are located at the corners of notches, away from the interfaces. Cracks initiate principally at these corners and propagate directly within the HAZ towards the sheet interface giving a full plug failure. (Ref 9).

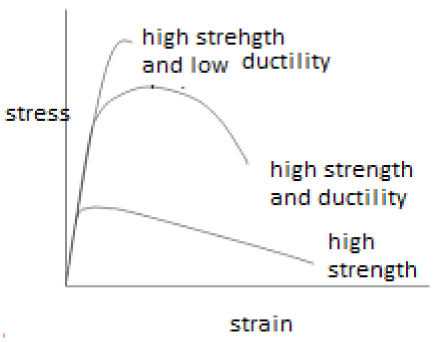

Fig4. Stress Strain curve of HSLA steels.

Due to the presence of hard martensite easier propagation of cracks and more readily generates interface failures. (Ref 10). The joint geometry, in terms of the weld diameter to sheet thickness ratio, also affects the fracture appearance of welds. For a low ratio, stress concentrations at the edge of the weld are high and weld cracking can initiate. A high ratio reduces the degree of stress concentration at the weld edge and can promote plug failure through the HAZ, rather than interfacial failure through the weld. Consequently, larger than normal weld sizes are sometimes suggested for HS steels.

3.1. Modification Of Fracture Mode

Notch sensitivity is one of the main factors in fracture of HSLA steels and it can be reduced by use of higher electrode force and welding time. The length of diffusion zone is increase but the notch sensitivity remains unchanged by increasing the diffusion zone, the stress level decreases by 30-40%. Increased welding time also increases the size and depth of HAZ and promote the tendency of plug fracture at the cost of weld strength. Welds produced with short hold times cools slowly and its ductility also increases, this reduces the quenching effect. But due to the short hold times weld nugget can be affected during cooling, especially in thicker sheet steels. Weld dilution can be done by inserting shim low carbon steel and it is obtained naturally in welding of low carbon steels. This insert can be practically applicable up to a certain limit and it has no effect on HAZ hardening.

4. METALLIC COATING IN WELDING OF HSLA STEELS

The contact resistance reduces due to higher conductivity and lower melting point of coating. Welding current increases and as compared to uncoated steels. Alloying of the coating with the spot welding electrodes also causes accelerated electrode wear. Many of the HS steels are available with a zinc coating, although the type of coating which is suitable may depend on the processing route of the steel, and the sensitivity to the thermal cycle associated with HDG (hot dipped galvanised) coatings. It is expected that coating the higher strength steels would not affect the microstructure of the steel itself, but that welding conditions would need to be modified to take account of the coating. However, there is a concern that the higher strength steels are more susceptible to surface cracking in the electrode indentation (associated with liquid metal penetration) than low carbon steels.

5. MECHANICAL PROPERTIES OF RESISTANCE SPOT WELDED STEELS WITH COMPARISON TO CARBON STEELS

It is known that HSLA steels require low force with high welding current to obtain the optimum weld quality. Shear stress bearing capacity of HSLA steels are better than the carbon steels and if plug diameter increases it also increase with it linearly, the increase of shear strength above 8000n/mm^2 has no effect on improved tensile strength as softening of HAZ also occurs. This softening of HAZ may results in improved overall ductility of weld but the chances of localized fracture increases and while designing the weld profile this effect has to be analyzed. Fatigue performance is also of in automotive applications. Preliminary work in this area found that high cycle fatigue strength of such joints under cross-tension and tensile-shear loading conditions was mainly dependant on the weld size and joint design, and less related to the strength of the parent steel. The fracture path in fatigue depended on the mode of loading, with fracture through the higher strength steel in shear and cross-tension but fracture through the lower strength steel in plane bending. Generally, the fatigue properties of the spot welded joints in HS steel sheets are no worse than those achieved with lower strength steels.

6. CONCLUSION-

The current study examines microstructure and mechanical properties of resistance spot welding of HSLA in optimum weld conditions and result are compared with the low carbon steels welding. The HSLA has more tensile strength in comparison to the low carbon steels. In comparison to conventional carbon steels these steels provide overall weight reduction possibility of vehicle. A slightly higher forces are required for better quality with HSLA steels as compared to low carbon steels and this increase of current is between 30-50%.

Weldability has one of the important factors for use of these steels in automotive industries when stresses are above $6000 N/mm^2$. High weld hardening and susceptibility to interface fracture can be the main problems that affect joint performance in some steels. The electrode forces used are nearly two to three times than that in low carbon steel welding with some modifications.

Generally, welds with nearly no imperfections are obtain by welding of high strength low alloy strength. This suggests that HSLA steels have good Weldability and could be used with easy to weld parameters as compared to low carbon steels.

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