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Resistance Spot Weldability of Low Carbon and HSLA Steels

S. P. Tewari
Reader in Mechanical Engineering Department IT BHU, Varanasi – 221005, India
E-mail: - sptewari_itbhu@yahoo.com

Nitin Rathod
M-Tech 2nd year Student in Mechanical Engineering,
(Production Engineering.) IT BHU, Varanasi – 221005, India
E-mail: - nitin_2nice@yahoo.com

Abstract

The resistance spot welding of dissimilar materials is generally more challenging than that of similar materials due to differences in the physical, chemical and mechanical properties of the base metals. The influence of the primary welding parameters affecting the heat input such as; peak current on the morphology, microhardness, and tensile shear load bearing capacity of dissimilar welds between Low Carbon steel and High Strength Low Alloy (HSLA) steel has been investigated in this study. This study has been done in three stages: First, welding performed on Low Carbon steel, then, on HSLA steel, after that, on a combination of both. During this study only welding current has been changed and other parameters are kept constant. Bearing capacity, hardness and weld nugget size of material shows a linear relationship with welding current, also weldability of low carbon steel with HSLA steel was found tobe satisfactory. At 8KA welding current, bearing capacity shows a maximum value (in Kg) of 270 for low carbon steel, 230 for HSLA steel, and 205 for a combination of both.

Keywords: Resistance Spot Welding, Weldability, Low Carbon Steel, HSLA Steel, Tensile-Shear Load, Welding Parameters, Mechanical Properties.

1. Introduction

Resistance spot welding is one of the oldest of the electric welding processes in use by industry today. It came into use in the period 1900-1905. The weld is made by a combination of heat, pressure and time. As the name resistance welding implies, it is the resistance of the material to be welded to current flow that causes a localized heating in the part. The pressure exerted by the tongs and electrode tips, through which the current flows, holds the parts to be welded in intimate contact, before, during, and after the welding current time cycle. The required amount of time current flows in the joint is determined by material thickness and type, the amount of current flowing, and the cross-sectional area of the welding tip contact surfaces [1, 2, 3, 4].

Although the problem of joining dissimilar metals is occurring with increasing frequency, not much valuable data in this respect are available. The reason is that each joint is really a special case, and both the metallurgical and design factors must be viewed, in terms of how the joint will operate under specific stresses and environments. Welding dissimilar metals has always presented a problem, due largely to the different ways in which metals respond to heat stresses and therefore the different strains on each side of the weld that joins them [3, 4].

In a joint between two dissimilar metals, the metallurgy of both base metals and the weld metal must be taken into account, because the weld metal is a composite of the fused base metals of three dissimilar metals and may actually be involved in these joints. It is often easier to make satisfactory joints between dissimilar metals by resistance welding than by arc welding, since the problem of fluxing or provision of an inert atmosphere does not arise, and the technique available often minimize the danger of the formation of brittle intermetallic compounds within the joint [3,4].

Steels with very low carbon content, usually up to 0.13% C, are good welding steels, but they are not the best for high speed production welding. Steels with very low carbon content are more ductile and easier to form than higher carbon steels. They are used for applications requiring considerable cold forming, such as stamping or rolled or formed shapes [4].

A group of low alloy steels that are designed to provide better mechanical properties and sometimes greater resistance to atmospheric corrosion than conventional carbon steels are known as HSLA steels. They are not considered to be alloy steels in the normal sense because they are designed to meet specific mechanical properties rather than a chemical composition. Carbon content of HSLA steels rarely exceeds 0.28% and is usually between 0.15% and 0.22% [4].

Strength of HSLA steels is between those of carbon steels and the high quenched and tempered steels. Typical applications of HSLA steels include support and panels for truck bodies, railways cars, mobile homes, and other transportation equipment. The weldability of most HSLA steels is similar to that of mild steels. HSLA steels can also be joined by a resistance spot welding process. When a spot welding process is used for these steels, they can be welded with about the same current and time setting used for low carbon steels. However higher electrode force may be needed because of the higher strength of these steels [4].

2. Materials and Experimental Methods

The dissimilar materials selected in the present work for the study are low carbon steel and HSLA steel. The chemical composition of both materials is shown in Table 1. Both materials were cut into pieces in dimensions of 100 mm x 30 mm x 3 mm. Before welding, the surfaces of the all samples were cleaned mechanically. Materials samples were spot welded in a stationary Rocker-arm, AC (alternating current) spot welding machine which is capable of 1–8 KA weld current as shown in Figure 1. Welding was carried out by using air cooled conical Cu–Cr electrodes having a contact surface diameter of 6 mm. Welding was performed by overlapping the plates linearly to fabricate the specimens for tensile shear test shown schematically in Figure 2. For the joining, 4, 6, 8 KA peak currents were applied while the other welding parameters were kept constant.

The tensile-shear test is the most widely used method for determining the strength of resistance spot welds. Tensile shear testing was carried out on the servo hydraulic type universal testing machine. This test is used mainly to establish ultimate shear strength when the specimen is tested in tension.

Hardness is the ability of a metal to resist penetration, to resist abrasive wear, or to resist the absorption of energy under impact load, accordingly these can be thought of as penetration hardness, wear hardness, and rebound hardness. Hardness measurement can provide information about the metallurgical changes caused by welding. The Vickers and knoop tests make relatively small indentations and are thus well suited for hardness measurement of the various regions of the HAZ for fine scale traverses. In the present work, Vickers hardness testing was performed by applying a load of 10 kg for 10 seconds.

3. Results and Discussion

The most important factors that affect weld quality are surface appearance, strength and ductility, weld nugget size, weld penetration, sheet separation, and internal discontinuities. Surface appearance of the welded dissimilar materials [5,6] is shown in Figure 3. Normally the surface appearance of a spot weld should be relatively smooth, round or oval in the case of contoured work, and free from surface fusion, electrode deposits pits, cracks and deep electrode indentation [5,6]. In this study, smooth weld surface appearance is almost obtained in the case of low carbon steel specimens. However, the weld surface appearance for HSLA is not as smooth as low carbon steel.

The nugget size is a critical parameter in the determination of spot weld quality. Therefore, the diameter or width of the fused zone must meet the requirements of the appropriate specifications or the design criteria [5,6]. The relationship between nugget size and peak weld current was determined in this study. The result is shown graphically in Figure 4. Results from Figure 4 also show that, increases in energy input, which was caused essentially by the enhancement of peak current, increases with the nugget size of the weld. Similar studies on different grade of steels by different researchers show that the enhancement of peak current increased the nugget size of the welded metals [6, 7, 8, 9, 10, 11, 12, 13, 14]. In this study, the nugget size of HSLA steel weld was found to be bigger than that of low carbon steel weld at the same welding current.

Penetration is one of the most important factors that affect the weld quality of spot welds. The penetration is the depth to which the nugget extend into the pieces that are in contact with the electrodes. The minimum depth of penetration is generally accepted as 20% of the thickness, while the depth of penetration should not exceed 80% of the thickness. Result from this study show that the penetration of weld was found to be between 20% and 80% of the thickness of the base metals for all weld current values [5, 6]. However, the penetration of the weld was increased by increasing peak weld current. Here one thing also can be noted, that the penetration of welding electrode in HSLA steel is more as compared to low carbon steel as shown in Figure5.

Blunt surface conditions, bigger nugget size and deeper electrode penetration as in the case of HSLA steel, when comparing to low carbon steel at same welding current, and even though welding electrodes have the same geometry. This may be due to more resistance between electrode and metal specimen as compared to the interface of both specimens. This leads to more heating between electrode and metal specimen, and hence is followed by formation of bigger nuggets and blunt surface conditions. Also, the hardness of HSLA steel (383.8 VHN) is more than low carbon steel (124.3 VHN), hence, electrode force does not get transferred properly on the weld zone, and causes deeper electrode penetration in metal. This difference in visual appearance, nugget size and electrode penetration of HSLA weld specimens implies that the resistance spot weldability of low carbon steel is better than HSLA steel as shown in Figure 5.

In order to determine weld quality of dissimilar materials, the strength of weldment was also determined. Structures employing spot welds are usually designed so that the welds are loaded in shear when the parts are exposed to tension or compression loading. In some cases, the welds may be loaded in tension, where the direction of loading is normal to the plane of the joint, or a combination of tension and shear [5, 6, 15]. In this study, the effects of peak weld current, on the tensile shear load bearing capacity of the dissimilar materials welds are given in Table 2. Results are also shown graphically in Figures 6, 7, 8 and 9. It is found that tensile shear load bearing capacity of welded materials increased with increasing peak weld currents. The enhancement in tensile shearing load bearing capacity of weldment with increasing of peak current is primarily attributed to the enlargement of nugget size [16, 17, 18].

From Figure 9, tensile shear load bearing capacity of low carbon steel is more than HSLA steel, followed by the combination of both materials. So it is understandable that the weldability of low carbon steel is more than that of HSLA steel, followed by the combination of these materials.

Ductility is also one of the most important factors that effects the spot weld quality. The ductility of a resistance weld is determined by the composition of the base metal and the effect of high temperatures and subsequent rapid cooling on that composition. The nearest thing to ductility measurement is the hardness test since the hardness of metal is usually an indication of its ductility [5, 6]. Therefore, the hardness measurement was performed on the weld nugget. The effect of peak current on the hardness across the weldment was determined and the result is shown in Figure 10. As seen in Figure 10, the increment in welding current results in an increase in the hardness of both materials. This increase in hardness value is mainly due to the increase in energy input, which causes more heating in specimens, and stress hardening takes place in the welding zone, due to the rapid cooling of weld metal.

Sheet separation is also one of the factors that affects the spot weld quality, occuring at faying surfaces, due to the expansion and contraction of the weld metal and the forging effect of the electrodes on the hot nugget [5, 6]. During this study, no separations were obtained. This may be due to higher thickness of welded specimens. The fracture characteristics of tensile shear specimens were also evaluated. Results show that failure occurred at the weld interface of welded materials. This also may be due to higher thickness of welded specimens.

4. Conclusion

By analyzing the results from various tests, this work can be concluded as follows:

The nugget size increases with increase in welding current value. Also nugget size of HSLA steel was found to be bigger than that of low carbon steel. This is because of, more resistance at electrode and HSLA steel interface, and also due to more hardness of HSLA.

It was found that the tensile shear load bearing capacity of welded materials increases with increasing peak weld current due to the enlargement of nugget size.

Resistance spot weldability of low carbon steel is more than HSLA steel, followed by weldability of the combination of these materials.

Hardness of materials increases with increase in welding current. This is because at high current value, heat generation due to welding is more, which is followed by increment in rapid cooling of material, thus, stress hardening takes place.

The failure of welded specimens occurred at the weld interface in all cases. This is due to higher thickness of welded specimens.

Higher welding current, bigger diameter electrode, more welding pressure and more welding time may give better results for higher thickness metals.

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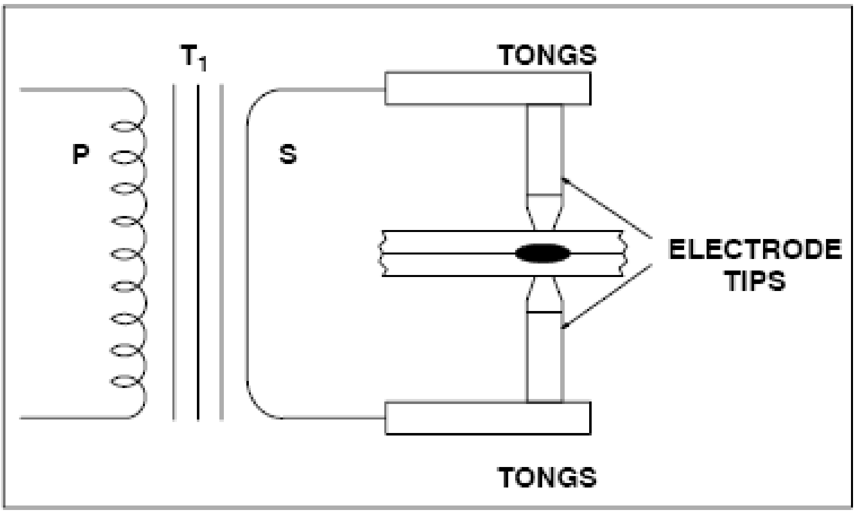

Figure 1. Resistance Spot Welding Machine with Work.

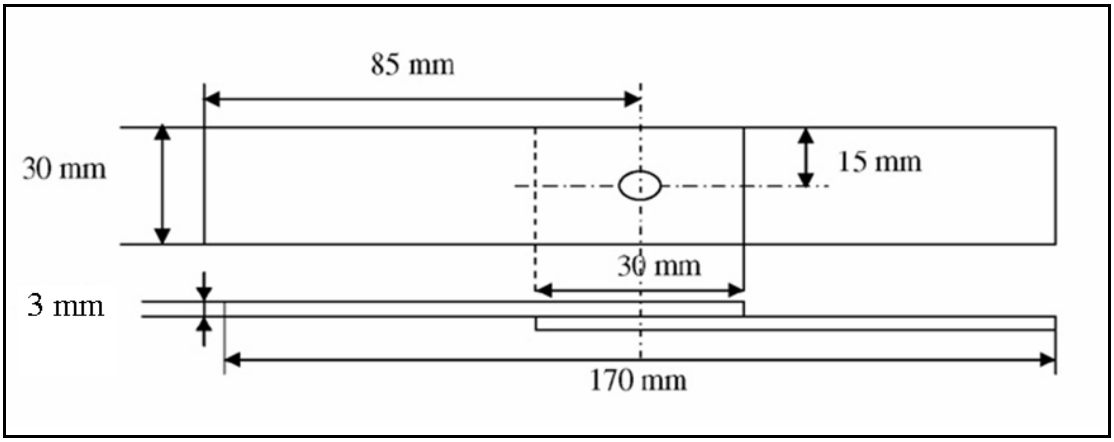

Figure 2. Tensile Shear Test Samples

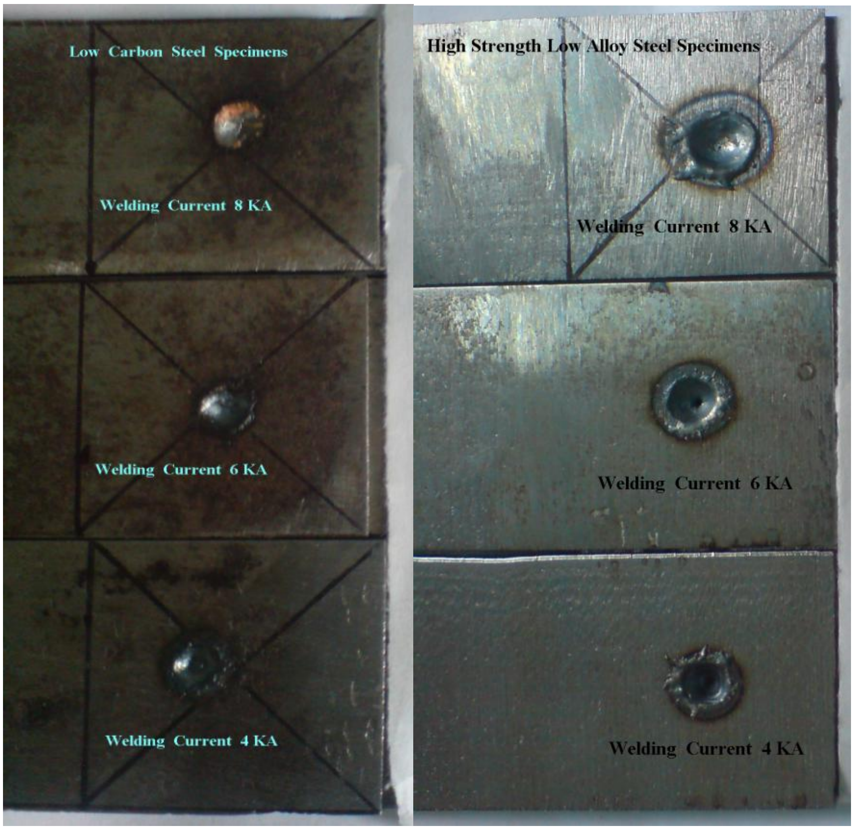

Figure 3. Low Carbon Steel Specimens and High Strength Low Alloy Steel Specimens.

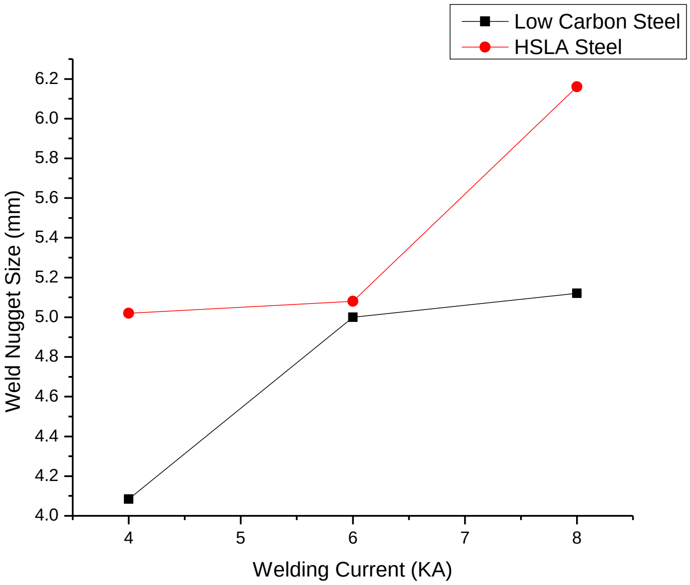

Figure 4. Variation in Weld Nugget Size with Variation in Weld Current

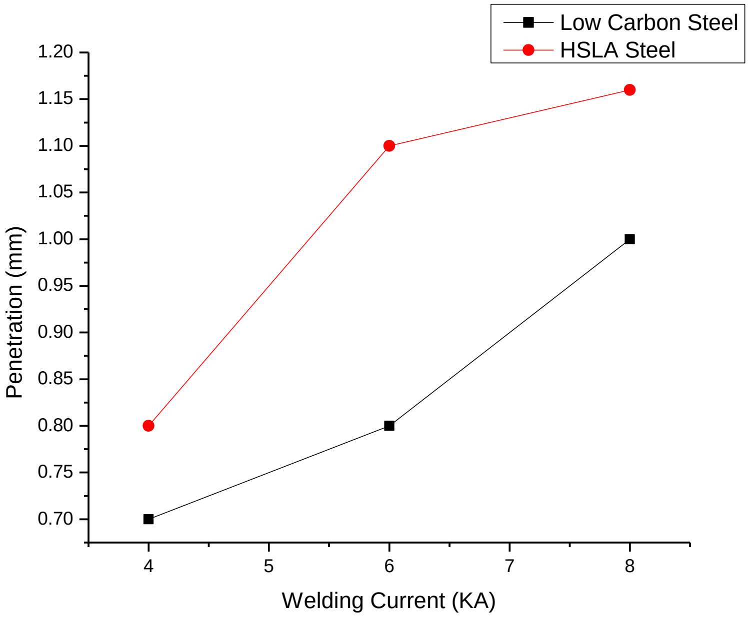

Figure 5. Variation of penetration with Welding Current

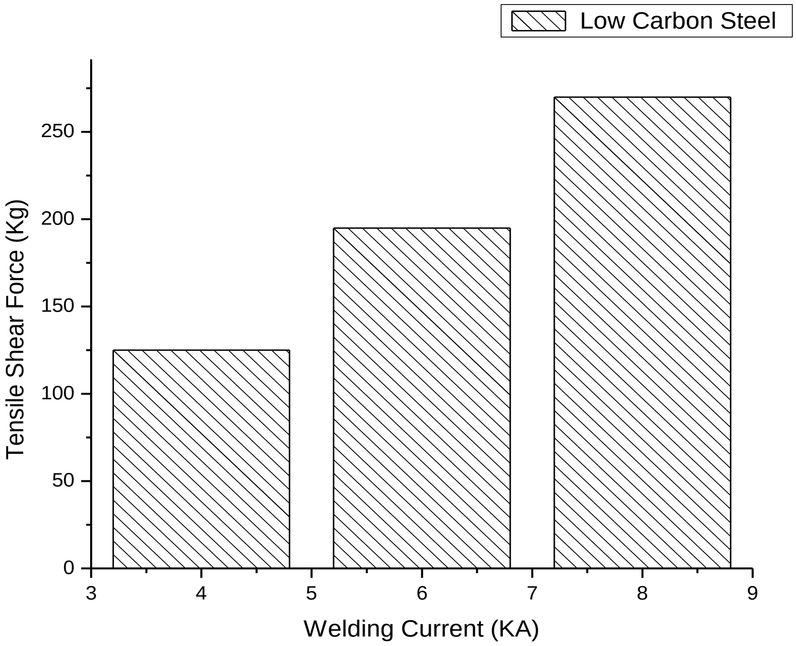

Figure 6. Tensile Shear Force Variation for Low Carbon Steel Specimens

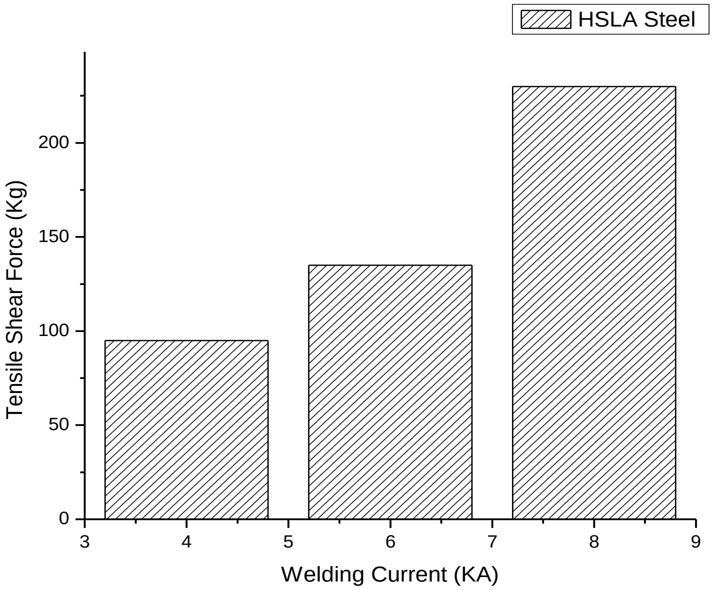

Figure 7. Tensile Shear Force Variation for HSLA Steel Specimens

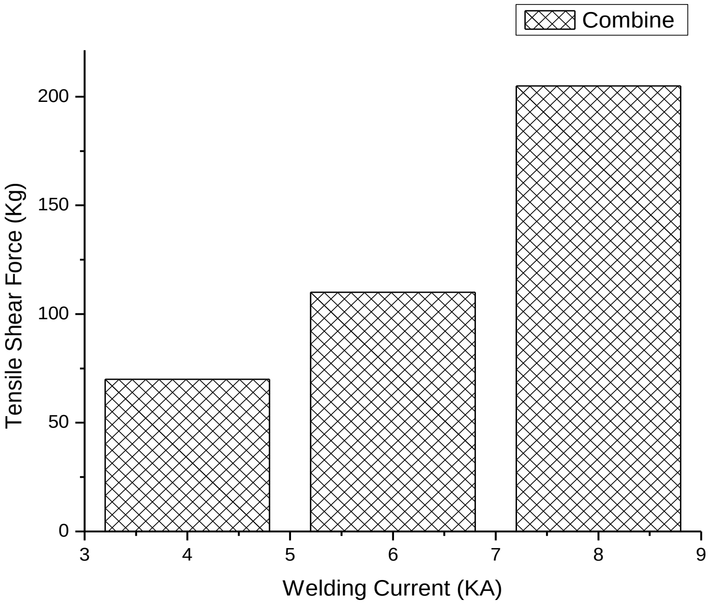

Figure 8. Tensile Shear Force Variation for Dissimilar Materials Weldment

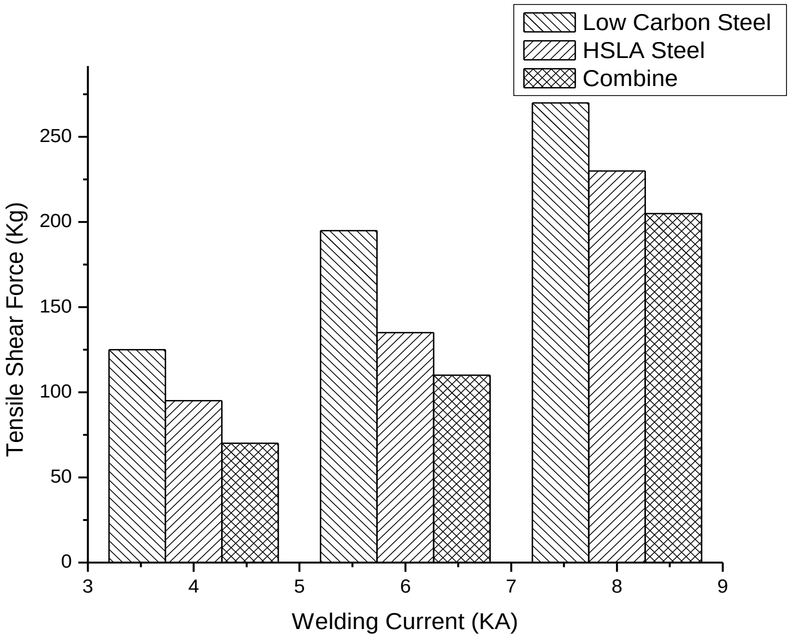

Figure 9. Tensile Shear Force Variation for All Materials Weldment

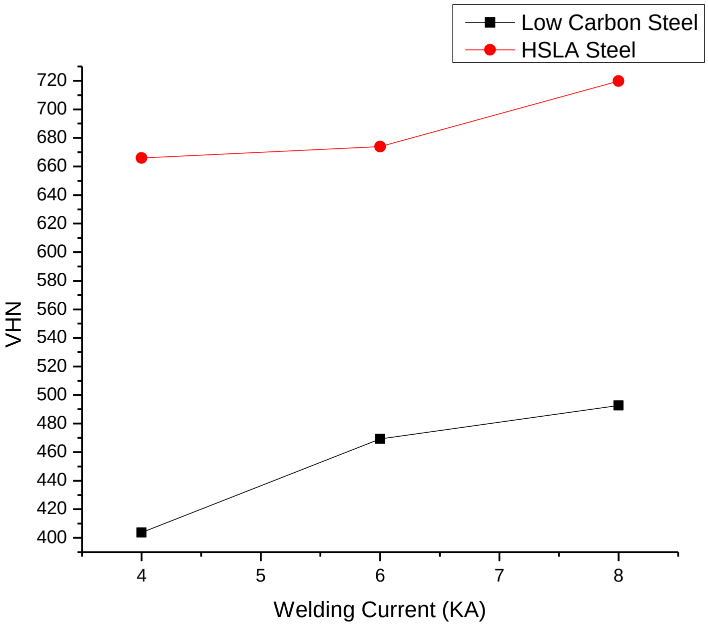

Figure 10. Hardness Variation According to Welding Current

Table 1. Chemical composition of materials (wt %)

Materials	C%	Si%	Mn%	P%	S%	Cr%	Ni%	Al%	Co%	Cu%	V%	W%
Low carbon steel	0.022	0.014	0.721	0.022	0.019	-	-	0.033	-	0.013	-	-
High strength low alloy steel	0.208	0.276	0.876	0.045	0.008	0.953	0.182	0.018	0.002	0.082	0.224	0.040

Table 2. Tensile Shear Strength Bearing Capacity

Materials → Welding Current ↓	Bearing Capacity of Low Carbon Steel Specimens (Kg)	Bearing Capacity of HSLA Steel Specimens (Kg)	Bearing Capacity of Dissimilar Materials Specimens (Kg)
4 KA	125	95	70
6 KA	195	135	110
8 KA	270	230	205