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Characterization and Analysis of Welding Area Between Alloy Steel Main Part and Bended End Part

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Abstract

In this study, 51CrV4 alloy steel bar was heated up to 900°C and rolled to produce round shape at the end of the steel bar. A gap takes place inevitably between the end and main part of steel. The gap should be closed by welding to avoid displace of bushing during the service life of tool. Therefore, rolled end part was welded to main body by gas-metal arc welding (GMAW-MIG) and the shielded metal arc welding (SMAW) methods. After filling the gaps, welded steels were annealed at 920°C for 50 minutes. In order to investigate the microstructure of welding regions, some samples were taken from welding areas. Present elements and chemical changing of the areas were analyzed by optical emission spectrometry. Sectional micro hardness was applied by Rockwell hardness unit. The residual stresses on the welded samples were investigated by X-ray stress analyzer based on solid state linear sensor technique.

Keywords: 51CrV4 alloy steel, MIG and SMAW, X-ray, Residual stress analysis

Çelik Alışımı Ana Kısımı ile Kıvrılmış Uç Kısım Arasındaki Kaynak Bölgesinin Karakterizasyonu ve Analizi

Özet

Bu çalışmada 51CrV4 alışım çeliğinden üretilmiş çubuklar 900°C'ye kadar ısıtıldı ve daha sonra bu çubukların uçları kıvrılarak sonlarında bir yuvarlak şekil oluşturulmuştur. Bu yuvarlak tamamen kapanmadığı için kaçınılmaz olarak ana malzeme ile ucu arasında bir aralık oluşur. Bu yuvarlak kısıma yerleştirilen burcun kullanım ömrü boyunca yerinden çıkmaması için bu aralığın kaynak ile kapatılmalıdır.
Dolayısıyla kıvrılmış uç ana gövdeye gaz altı ark kaynağı (GMAW-MIG) ve korunmalı metal ark kaynağı (SMAW) metotları ile birleştirilmiştir. Aralıklar doldurulduktan sonar kaynaklanmış çelikler 920°C'de 50 dakika tavlanmıştır. Kaynak bölgelerinin mikroyapısı incelenmesi için örnekler alınmıştır. Optik emisyon spektrometresiyle kaynak ve çevre bölgelerindeki mevcut elementler ve kimyasal kompozisyon değişimi analiz edilmiştir. Rockwell sertlik yöntemiyle kesit alanın mikro sertlikleri ölçülmüştür. Kaynak numunelerindeki kalıntı gerilimleri X-ışını stres analizörünün katı hal doğrusal sensör tekniği ile araştırılmıştır.

Anahtar Kelimeler: 51CrV4 alaşım çeliği, MIG ve SMAW, X-ışını, Kalıntı stress analizi

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1. INTRODUCTION

Welding is a fabrication process to make high strength joint between two or more parts by heating to their melting temperature, with or without the application of pressure and with or without the use of filler metal. The filler metal has a melting point approximately same as the base metal. Welding has become highly automatized over the last decade, and the use of robots is now commonplace in certain industries, such as the automotive manufacturing plants. It is possible to weld items in unusual conditions, including underwater and in outer space [1-3].

Gas-Metal Arc Welding (GMAW) is also called the Metal Inert Gas (MIG) welding, an electric arc is established between the work piece and a consumable bare wire electrode. The arc continuously melts the wire as it is fed to the weld puddle. The weld metal is shielded from the atmosphere by a flow of an inert gas, or gas mixture. This maintains the strength and durability of the weld metal [1-3].

Shielded Metal Arc Welding (SMAW) is performed with the heat of an electric arc that is maintained between the end of a coated metal electrode and the work piece. The metal electrode has a solid coating of inert materials which vaporizes as you weld. This creates an inert cloud or gases which protect the molten metal and displace any oxygen that might come into contact with it [1-3].

SMAW and MIG welding processes are extensively used to joint different materials. Pathak et al., [4] used these methods to joint austenitic stainless steel. In another study, Gürsel and Kurt [5] SMAW welded SS30-type stainless steel and A36 low-carbon steel.

Heat from welding may cause localized expansion, which is taken up during welding by either the molten metal or the placement of parts being welded. When the finished weldment cools, some areas cool and contract more than others, leaving residual stresses. In measuring residual stress using X-ray diffraction (XRD), the strain in the crystal lattice is measured and the associated residual stress is determined from the elastic constants assuming a linear elastic distortion of the appropriate crystal lattice plane. Residual stress diffractometers can be divided into two types Fixed, laboratory based systems and Portable systems. The portable system can be taken to a large structure (for example, a bridge) and placed on the component of interest. The instrument shown is an omega diffractometer. The sample remains stationary, only the assembly carrying the tube and detectors moves, allowing the machine to accommodate very bulky samples, or even to be placed onto a large structure [6].

51CrV4 alloy steel group is particularly being used for components subject to high stress, thus when a combination of high strength (wear resistance) and good toughness is crucial. Because of their chemical composition are suitable for hardening, and in the quenched and tempered condition have good toughness at a given strength [7]. The material receives its special characteristics through quenching and tempering. The processors need to make sure that their calculation method, design technique and processing procedure are aligned with the material. Precise temperature control is crucial for the part’s characteristics. Therefore, the temperature needs to be adjusted according to the respective purpose of the material [8].

Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. Leaf springs are designed according to axle where they assembled. A leaf spring which is used for this study has a round shape each side of it. Round shape is called eye in industry. Bushing is fixed into the eye. After that leaf spring is assembled to axle by inserting pin through the bushing. Centrifugal force is applied on bushing when the vehicle is at curb position especially on the winding road. Bushing might be off under this force. The gap between eye and base material can be ease bushing out therefore the gap is filled by using welding to prevent bushing out. The main objective of this work was to experimentally investigate the microstructure and mechanical properties of the welded joints prepared by SMAW and MIG welding processes.

2. EXPERIMENTAL

In this study, 51CrV4 alloy steel (base metal) bar was heated up to 900 °C and rolled to produce round shape at the end of the steel bar. A gap takes place inevitably between the end and main part of steel. The rolled end part was welded to main body by using two different types of welding method. The first one is metal–inert gas (MIG) method and the second method is the Shielded Metal Arc Welding (SMAW) method with supercito basic electrodes. Schematic illustration of rolled and welded steel bar was given in Figure 1. After filling the gaps, welded steels were annealed at 920°C for 50 minutes. The steel bars were quenched in oil (at 60^{o}C). The bars were tempered at 425^{o}C for 120 minutes. In order to investigate the microstructure of welded regions, transition regions and main steel parts, some samples were taken. The samples were ground, polished and etched before microscopic inspection. Grain size were measured by image analysis program (NIS-Elements D, Nikon). Present elements and chemical changing of the areas were analyzed by optical emission spectrometry. Sectional micro hardness was applied under 1 kg pressure by Rockwell hardness unit. The residual stresses on the welded samples were investigated by X-ray stress analyzer (Stresstech, Xstress 3000 G2) based on solid state linear sensor technique. Figure 2 shows the X-ray stress analyses of welded samples.

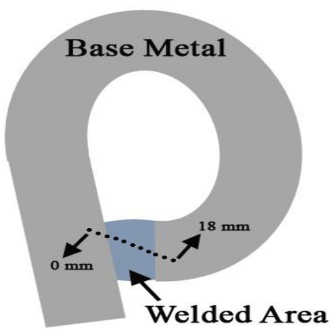

Figure 1. Schematic illustration of rolled and welded steel bar

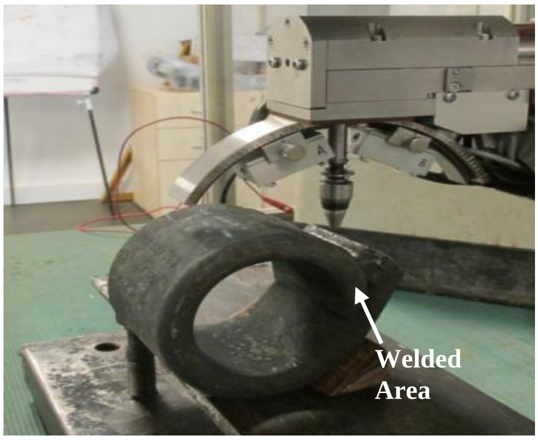

Figure 2. Residual stress measurement

3. RESULTS AND DISCUSSION

Chemical composition of welded and main steel parts of materials were measured and the results were given in Table 1. According to elemental analysis of regions, carbon and silicon ratios were significantly different than base metal.

Residual stresses were analyzed welded areas and base metal by portable X-ray analyzer. The mean residual stress were given in table 2. According to results, compressive stresses were present at welded areas but tensile stress was present on the base metal.

Table 1. Chemical composition of welded regions and base metal

Quantity %	Base Metal	MIG Welded Area	SMAW Welded Area
C	0.549	0.197	0.252
Si	0.269	0.305	0.155
Mn	0.862	0.654	0.544
P	0.046	0.0149	0.015
S	0.001	0.0089	0.004
Cr	1.170	0.329	0.350
V	0.149	0.0363	0.0282

Table 2. Residual stress analysis

Material Regions	Mean Residual Stress (MPa)	Std. Deviation (MPa)
Base Metal	39.8	16.10
MIG Welded Area	-226.6	48.73
SMAW Welded Area	-140.0	25.20

Figures 3 and 4 show the microstructures of polished and chemically etched surface of welded regions and base metal. The microstructures of the base metal was almost martensitic with some ferrite phases (Figs 3a and 4a). On the other hand, SMAW and MIG welded areas composed of pearlite and ferrite phases. In higher magnification (500X) at figures 3 (b, c) and 4 (b, c), ferrite phase is white grains and gray regions are perlite phase. In figures 5 a and b, heat affected zone between base metal and MIG welded area or SMAW welded area are demonstrated, respectively.

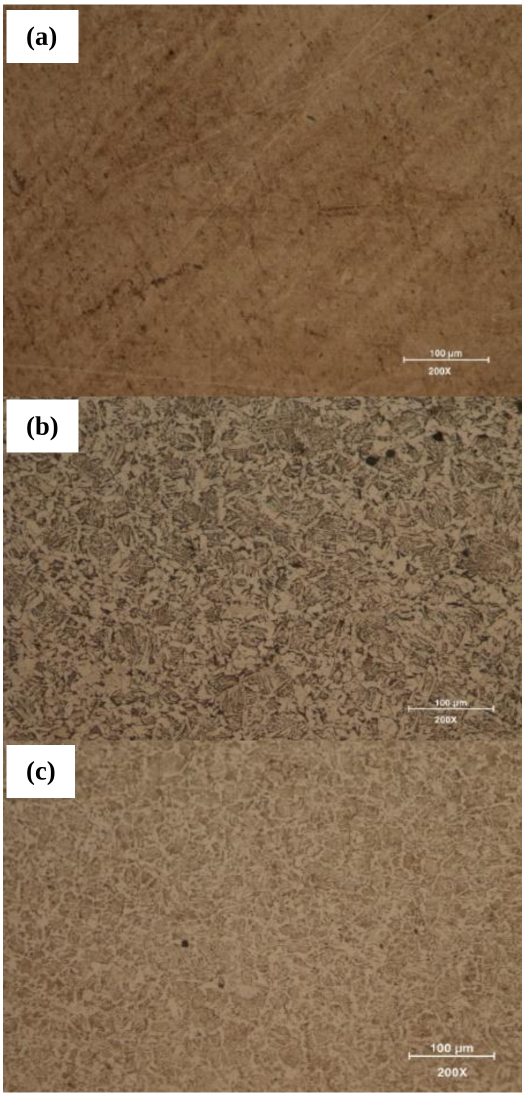

Figure 3. Microstructures of regions at 100 X magnification a) Base metal, b) MIG welded area, c) SMAW welded area

Grain size of base metal, MIG and SMAW welded areas were measured with image analysis program. Figure 6 shows representative selected images for the base metal, MIG and SMAW welded areas. The grain size results were tabulated in Table 3. According to the results, grain size of base metal and SWAM welded area are nearly same value of 26 µm. But, MIG welded area has lower grain size than the other areas.

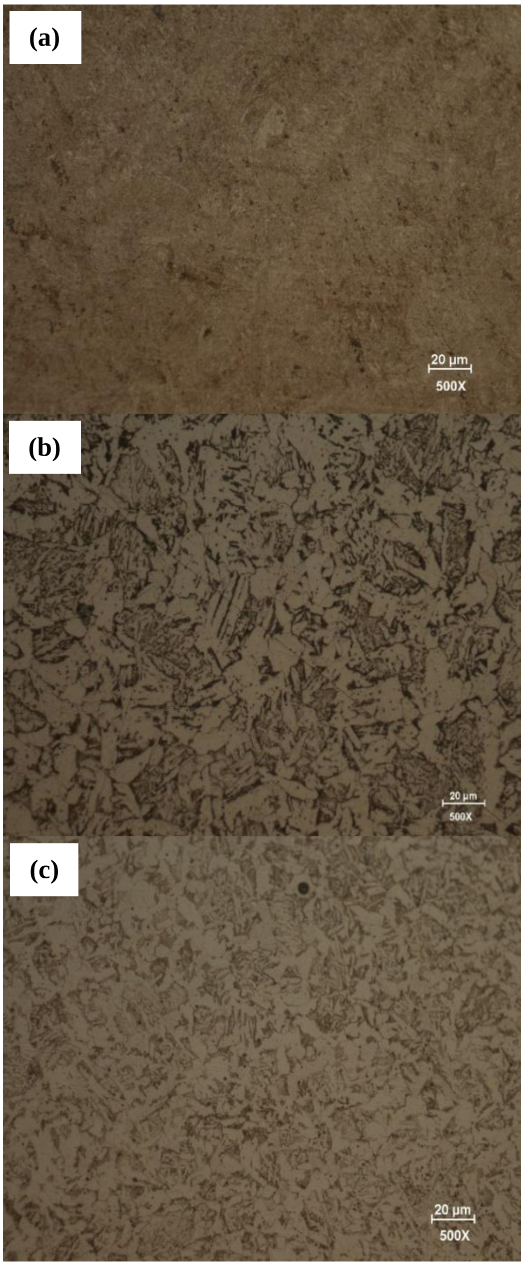

Figure 4. Microstructures of regions at 500 X magnification a) Base metal, b) MIG welded area, c) SMAW welded area

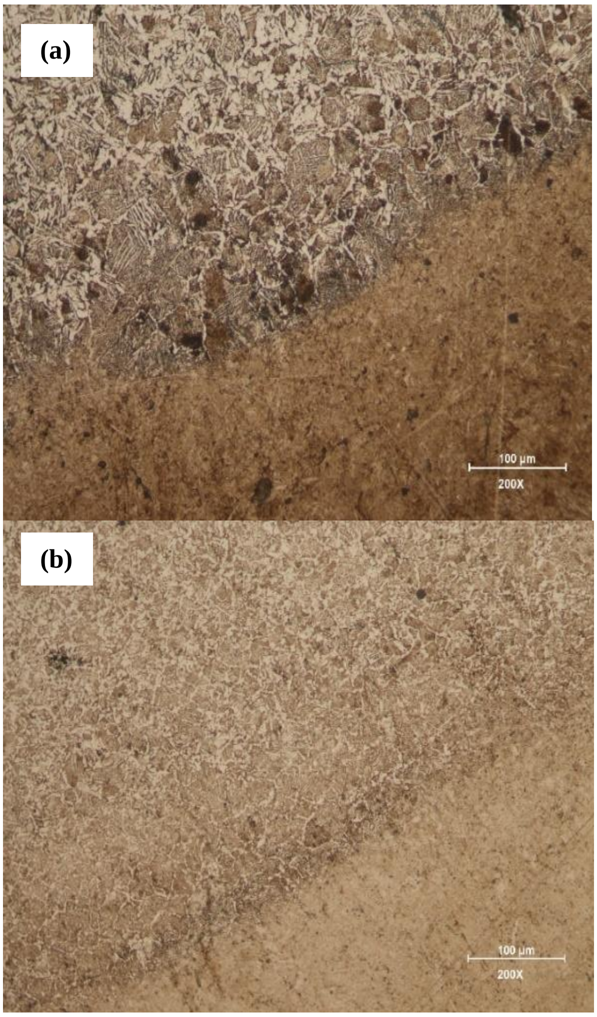

Figure 5. Heat affected zone between base metal and a) MIG welded area, b) SMAW welded area

Hardness is an important factor in controlling the quality of a weldment. Strength/hardness mismatch between various micro-structural regions significantly affects the fracture behavior of a weldment. The Vickers hardness testing machine was used to test the hardness. Representative indentation marks are shown for the base metal, MIG welded and SMAW welded areas in Figure 7. Indentation mark of base metal is smaller than welded areas means that hardness of it higher than the others.

The hardness of base metal, heat affected zone, and welded area were measured starting from one side of base metal to the other side of base metal by passing welded areas. The starting point (0 mm) and end point (18 mm) are depicted also in Figure 1. The hardness results are plotted in Figure 8. According to graph, the base metal hardness is around 493 Vickers, the heat affected zone hardness is around 300 between base metal and SMAW welded area. The heat affected zone hardness is around 265 between base metal and MIG welded area. Depend on the welding method, the hardness slightly changes from 215 to 173 Vickers for SMAW and MIG welded areas, respectively.

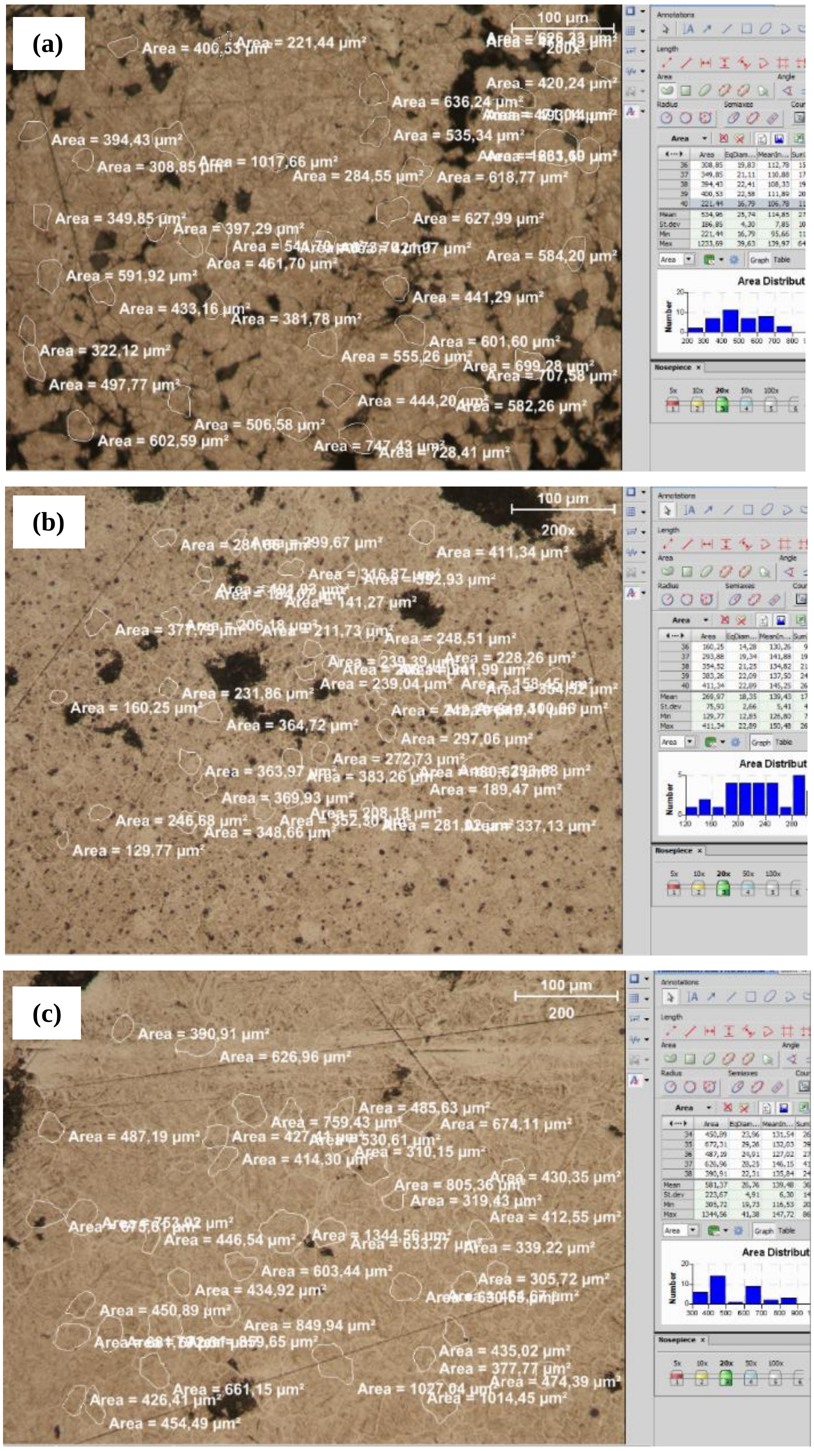

Figure 6. Grain size measurement at 200 X magnification a) Base metal, b) MIG welded area, c) SMAW welded area

Table 3. Grain size measurement results

Material	Grain Size (μm)	Std. Deviation (μm)
Base Metal	25,74	4,30
MIG welded area	18,35	2,66
SMAW welded area	26,76	4,61

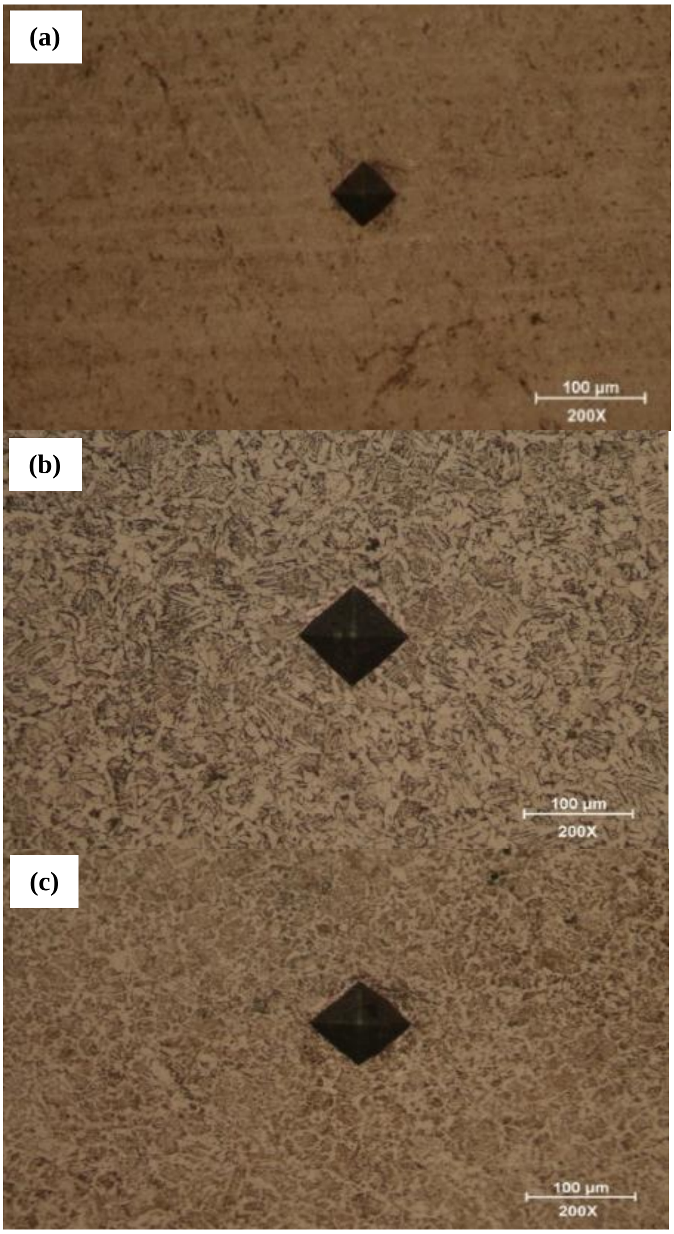

Figure 7. Vickers indentation marks at 200X magnification a) Base metal, b) MIG welded area, c) SMAW welded area

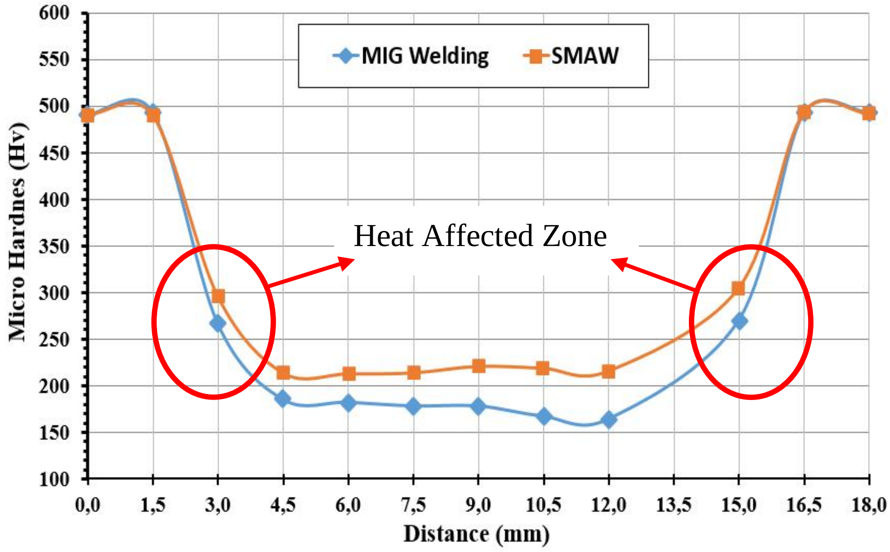

Figure 8. Micro hardness distribution of base metal, SMAW and MIG welded areas

4. CONCLUSION

In this study, 51CrV4 alloy steel bar was rolled to produce round shape at the end of the steel bar rolled. The rolled end part was welded to main body by using MIG and SMAW welding methods. The microstructure and mechanical properties of welded areas were experimentally investigated. Martensitic phase was observed in the base metal, on the other hand ferritic and pearlitic phases were detected in the welded areas. Base metal and SMAW welded areas were measured nearly same grain size values. Welded areas subjected to under compressive residual stress in contrast to base metal. MIG welded area has the highest compressive values. Base material mechanical properties is closed to SWAM welded area but they are higher than MIG welded area. In terms of preferring 51CrV4 for leaf springs, SWAM welding might meet requested specification.

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