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WeldabilityofOptim700 MC-St37 Steel Pairby Plasma Transfer Arc (PTA) Welding Method

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Abstract—In this study, the weldability of OPTIM 700 MC and St37 steels with different properties by Plasma Transfer Arc Welding (PTA) was investigated. In the study, welding speeds of 0.15 m/min., and 90 A, 100 A, 110 A, and 120 A Ampere values were used. The strength of the joints was tested with tensile test. Microhardness measurements were performed in Vickers scale under aload of 500 g. Microstructure changes in the weld zone of Post-weld production parameters were investigated by optical microscope, SEM-EDX, and XRD analyses. From the metallurgical point of view, the highest level of welding qualities were observed in the sample 4 (120 A).

Index Terms—Optim 700 MC, St37, PTA, Weldability, Mechanical Properties.

1 Introduction

Plasma transfer arc welding (PTA) is a gas-shielded arc welding method where the tungsten electrode and work-piece are welded with arc heat [1]. Its strength is high in terms of arc stability and current, more penetrating welding seams occur and the arc can be held easily, and control and also the weld time decrease during its usage. The plasma tungsten arc (PTA) method is one of the widely used basic methods. High energy input as well as the low cost and simplicity of the system attract attention as an advantage [2]. St37 steels are structural steel type with tensile strength of 37 kgf/mm2according to DIN 17100 standard used commonly in steel constructions [3]. Optim 700 MC is a hot-rolled (M) and cold-formable (C) steel exceeding EN standards. Optim 700 MC is a steel having high strength steel quality, perfect bendability, weldability, and cutting properties. It has the advantages like lightweight structures, increased loads for machinery and equipment and low fuel consumption in vehicles. It is sensitive to the environment and can be recycled. It is a steel having surface quality and dimension that can be shaped geometrically [4].

Correa et al., investigated the weldability of iron-based powder materials by using the pulsed plasma arc welding method [5]. Ozel et al., investigated the microstructural characteristic of NiTi coating on the stainless steel surface with plasma transfer arc welding. In this study, NiTi powders were surface-coated on AISI 304 austenitic stainless steel surface by using plasma transfer arc (PTA) welding at 80-90-100 A current under Aratmosphere [6]. Kurt et al., examined the effect of austenitic interface layer on the microstructure of AISI 420 martensitic stainless steel joined by keyhole PTA welding process. In this study, a 10-mm thick AISI 420 martensitic stainless steel material pair and 2-mm thick austenitic stainless steel intermediate layer were joined by using the keyhole PTA welding [7]. Kahramanet al., examined the effect of welding current in pure titanium plasma arc welding. In this study, they investigated the effect of welding current in plasma arc welding of pure titanium having athickness of 1.5 mm [8]. A.K. Gur et al., examined the weldability of Ti6Al4V Alloy pairs byPlasma Tungsten Arc (PTA) welding method and determined that Ti6Al4V alloy pair can be successfully welded byusing PTA welding method [9]. In their study, A.K. Gur et al., examined the joining properties of welding of AISI 430/304 steel pair by using Plasma Transfer Arc (PTA) welding method. The experiments were carried out at a fixed feed rate and different amperes under Ar atmosphere. After the welding processes, the joining zone was examined macroscopically and microscopically [10]. In their study, H. Dikbas et al., investigated the weldability of AISI 430/304 steels by Plasma Tungsten Arc (PTA) weld method. The experiments were carried out under argon-nitrogen atmosphere at different ampere values and fixed welding speed [11]. In their study, A.K. Gur et al., examined the joining properties of AISI 304/Hardox 400 steel pairs by using PTA welding method. The study was conducted with fixed welding speed and at constant amperage value under Ar atmosphere [12]. In their study, U. Caligulu et al., investigated the results of joining of P460 steel joinedusing the submerged arc welding (SAW) weld in X-Ray radiographic test. P460 material pairs were welded at different welding speed and ampere values using the submerged arc welding method. In these welded samples, Notch impact test, microhardness measurement, X-ray diffraction method, and radiography tests were examined [13]. In their study, U. Caliguluet al., investigated the effect of ampere values on joining of P460and St52 (S355J2G3) material pairs with different properties by using submerged arc welding method [14].

The purpose of this study is to join St37 steel having usage areas in the market with OPTIM 700 MC steel at different welding parameters by using Plasma Transfer Arc Welding Method. Even though gas metal arc welding (MIG-MAG) used in welding of automobile parts is suitable for automation, additional metal residues can be left after welding and final cleaning process may be required. Plasma arc welding can be used to minimize this disadvantage.

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2 Experimental Procedures

In this study, the samples obtained from the market were processed in a CNC machine and the welded joining samples were prepared. The prepared samples were numbered in accordance with the experimental design program. Table 1 shows the chemical analyses of the materials used, Table 2 shows mechanical properties, Table 3 shows the welding parameters used, Table 4 shows welding parameters in PTA welding. Metallographic examination procedure was applied to the samples.

Table 1. Chemical compositions of the experimental materials

Materials	*C*	*Si*	*Mn*	*P*	*S*	*Al*	*Fe*
OPTIM 700 MC	0,10	0,20	2,10	0,02	0,01	0,015	remain maining
St37	0,17	-	-	0,4	0,40	-	remain maining

Table 2. Mechanical properties of the experimental materials

Materials	*Tensile strength(MPa)*	Yield Strength *(MPa)*	Elongation *(%)*
OPTIM 700 MC	750-930	700	13
St37	350 - 480	235	25

Table 3. Welding parameters

Sample	*Power(Ampere)*	*Feed rate (m/sec)*
1	90	0,15
2	100	
3	110	
4	120	

Table 4.Welding parameters in PTA welding

Shielding Gas Flow Rate (L/min) Ar	*8*	*OPTIM 700 MC- St37*
Plasma Gas Flow Rate (m^3/ h) Ar	*0,5*	
Electrode Diameter (mm)	*4,7*	
Electrode	*% 2 tungsten electrode with thorium*	
Torch Material Distance (mm)	*3≈4*	
Torch Tip Diameter (mm)	*3,25*	
Set-Back (mm)	*4*	

The tensile test was carried out to determine deformation behavior (mechanical properties) during the loading process and load carrying capability of the obtained welded joints. The experiment was carried out in the tensile device having a load capacity of 50 kN at 1 mm/mintensile rate and in accordance with TSE 138 EN 10002-1 standard. Microhardness measurements were performed in Vickers scale under a load of 500 g. Microstructure changes of production parameters occurring in joining zone after welding were examined by optical microscope, SEM-EDX,and XRD analyses.

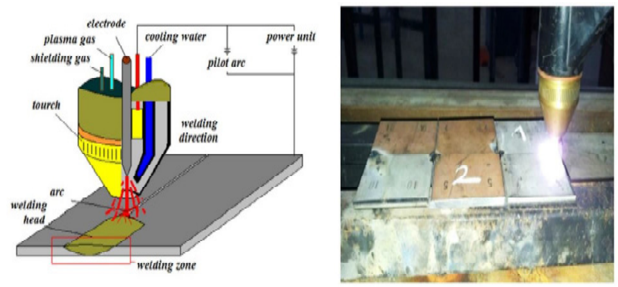

Fig.1. Schematic view of PTA welding and Image of PTA welding process [15].

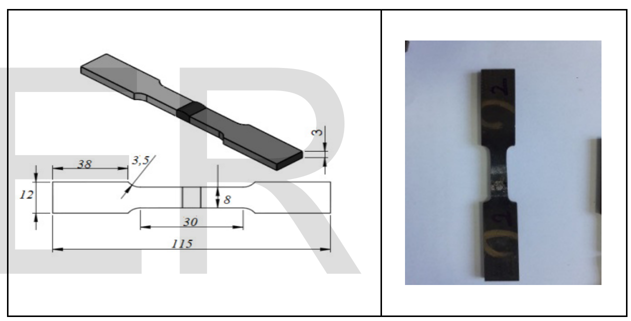

Fig. 2. Sizes of sample of tensile test and tensile sample

3 Results and Discussion

3.1 Evaluation of Microstructures

The structural changes occurring in the joining zone of the samples welded by using Plasma Transfer Arc Welding method were evaluated by examining the microstructure images from the base metal and transition zones with weld zone (HAZ) taken from these samples. The microstructures of OPTIM 700 MC and St37 steels used in this study contained ferrite and perlite phases.

When the joints made with different welding power to the steel pairs were examined in metallographic way, it was observed that the welding seam had a homogeneous appearance and the penetration increased depending on the welding power applied.

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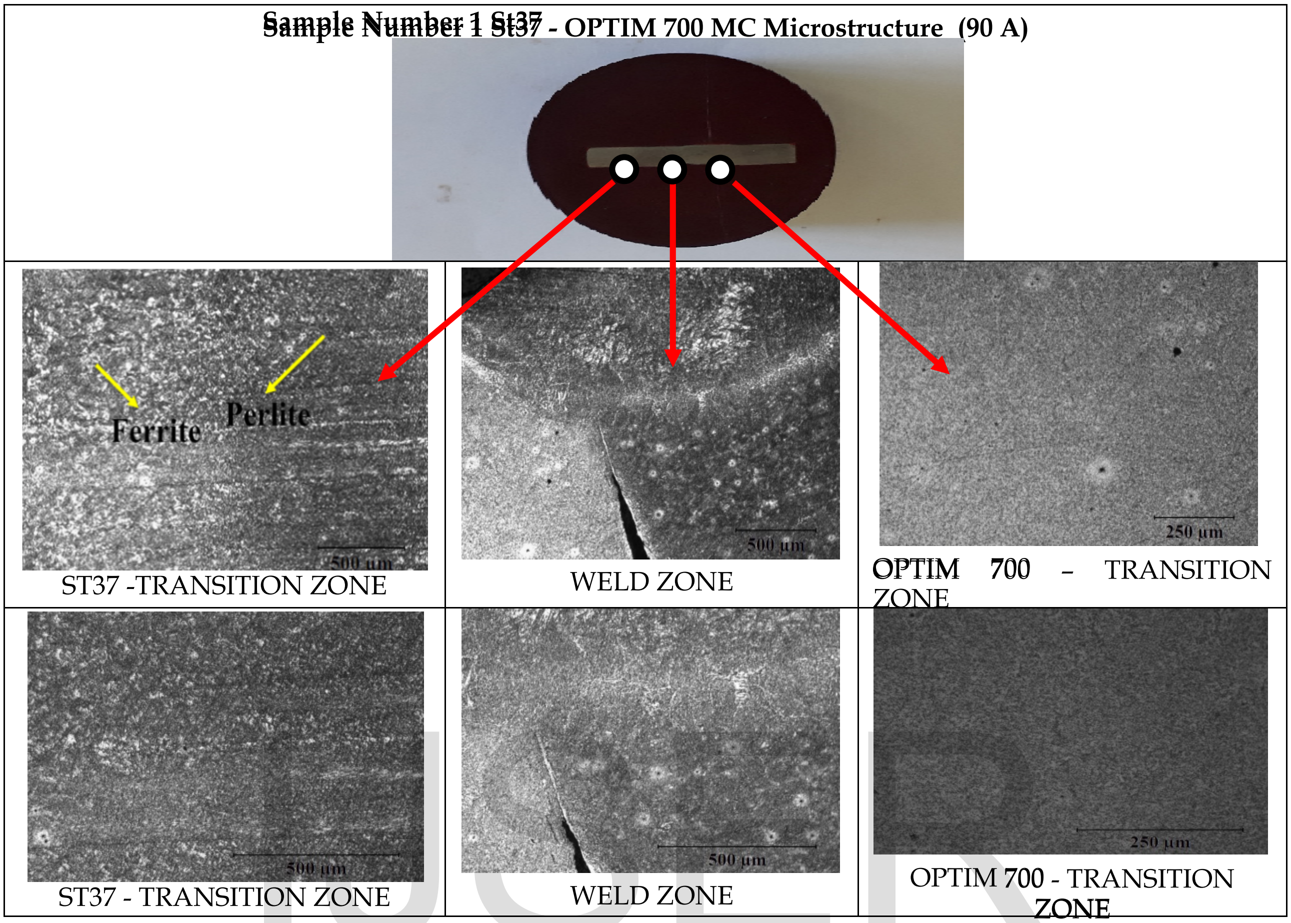

Fig. 3. Sample Number 1 St37 - OPTIM 700 MC microstructure (90 A)

Joints made with the values lower than 90A were observed to be insufficient joints. It was also determined that the materials were deformed in joints welded with the values higher than 120A. No crack formation was observed in the joining. Not having any crack in the weld zone signified that no intermetallic phases formed. As is seen in the microstructure images, the solidification started from the base metal and vertically moved to the weld point. This kind of solidification type was evaluated as epitaxial solidification. The grains in the points having more heat input and being under the annealing effect formed coarser. The best joint was observed in the sample number 4 made at 120A.

3.2. Tensile Test Results

In the examination made in this study, it was determined that the samples number 1 and number 4 welded at 90A and 120A were fractured without giving neck in the applied tensile test.

When the figures were examined, it was determined that the sample number 4 cannot show a complete joint due to the cavities in the welding. Rupture with necking was observed in the cracking occurred in the joint made with 100A and 110A. Therefore, it can be asserted that these material pairs ruptured with the ductile fracture mechanism in their current form. Because ductile fracture occurs after high amount of plastic deformation and it is seen as a conical bowl shape on the fractured surface of the material. SEM images of the fracture surface taken from rupture surfaces of St37 and OPTIM 700 MC steel pair also supported the ductile fracture. The fracture surface had a spongy rough structure. This indicated that there was a ductile fracture mechanism.

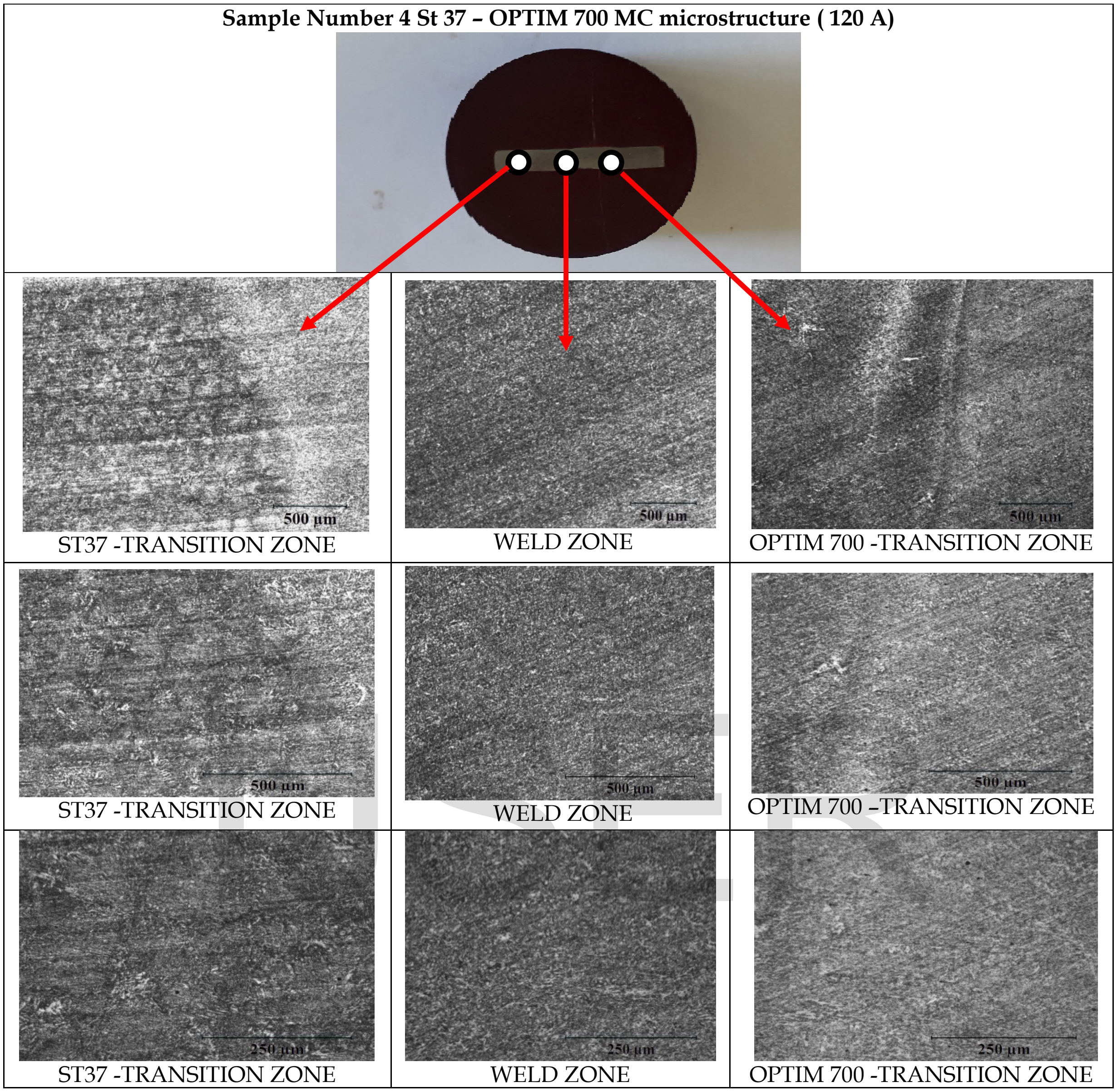

Fig. 4. Sample Number 4 St37 - OPTIM 700 MC microstructure (120 A)

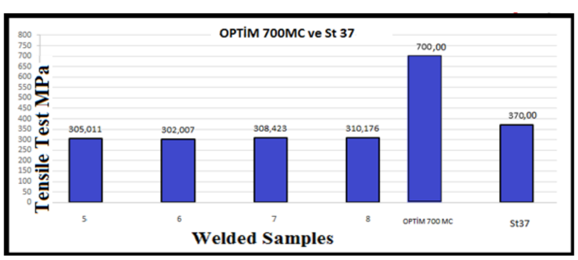

Fig. 5. Tensile graphs of the samples

3.3. Evaluation of Microhardness

As a result of the microhardness measurements performed in steel pairs, hardness value in HAZ was observed to increase compared to the hardness value of St37 and OPTIM 700 MC base material. This was thought to be arising from hard and brittle intermetallic phases in the weld zone of the samples St37 - OPTIM 700 MC. High heat input that exists in the mechanism of the Plasma Transfer Arc Welding causes sudden hardening in the welding seams during cooling. Lack of a controlled cooling in the heat input causesa slight increase in the hardness value in HAZ.

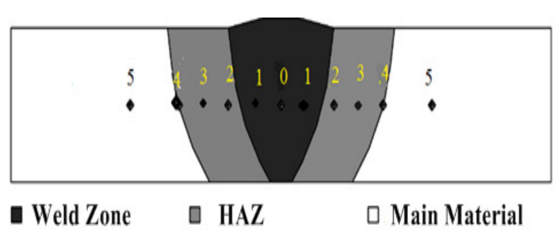

Fig. 6. Schematic view of micro hardness measurement points.

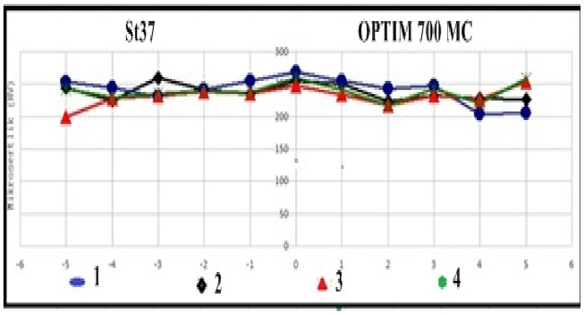

Fig. 7. Microhardness graph of St37- OPTIM 700 MC samples

3.4. Fracture Surfaces Analysis

Elemental transitions in St37 and OPTIM 700 MC materials used in the study were calculated by EDS analysis. EDS analysis was taken with full screening. As a result of this analysis, the highest elemental change (%) was determined in Fe and C elements. As a result of EDS analysis, it was found that while Fe element was 81.67% in St37 steel and77.12%inOPTIM 700 MC steel, C elementwas 17.05% for St37 and 19.70%for OPTIM 700 MC steel. The presence of 2.32% Mn element in OPTIM 700 MC steel showed that the strength and weldability of steel increased. When the fracture surface and SEM images of the material were examined, the formation of ductile fracture mechanism was observed. The factors and ratios determined in EDS analysis are given below.

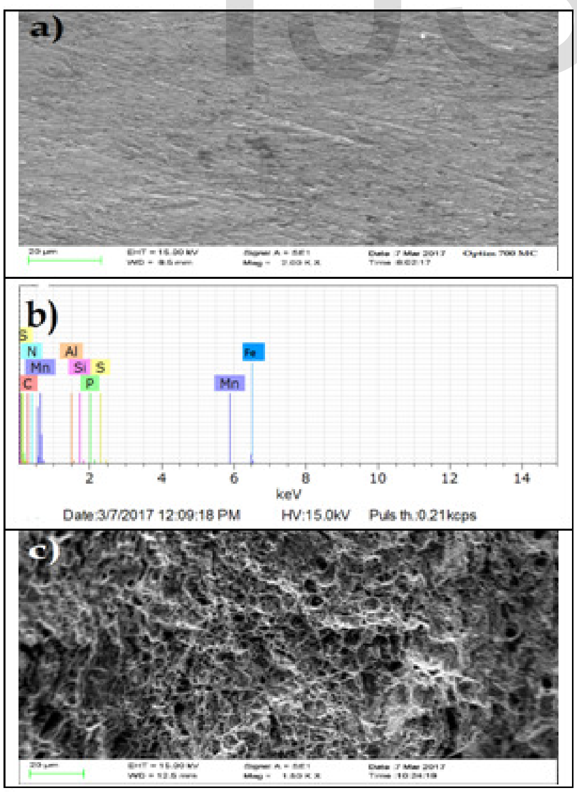

Fig. 8. a)SEM image b)EDS graphc) Fracture surface image (120A)

TABLE 6. EDS ANALYSIS RESULTS

	Weight %		Atomic %	
Element	*St37*	*OPTIM 700 MC*	*St 37*	*OPTIM 700 MC*
C	*17.05*	*19.70*	*52.54*	*52.61*
Si	*0.21*	*0.28*	*0.25*	*0.26*
Mn	*0,18*	*2.32*	*0.08*	*0.69*
Fe	*81.67*	*77.12*	*46.14*	*46.41*
P	*0.12*	*0.28*	*0.53*	*0.16*
S	*0,45*	*0.12*	*0.24*	*0.11*
N	*0.32*	*-*	*0.22*	*-*
Al	*-*	*0.18*	*-*	*0.12*
Totals	*100.00*	*100.00*	*100.00*	*100.00*

3.5. Examination of XRD Analysis Results

When the XRD analysis of the material was examined, ferrite and perlite phases were detected in St37 and OPTIM 700 MC steels. After XRD analysis, Mn5Si2, Mn Si, Fe3C, and Fe phases were determined at welded joints.

The phases obtained as a result of XRD are not fragile intermetallic phases. This is because there was no crack formation in the transition zones and the formation of ductile fracture mechanism supported this situation. Figure 9 shows the result of XRD analysis of the samples.

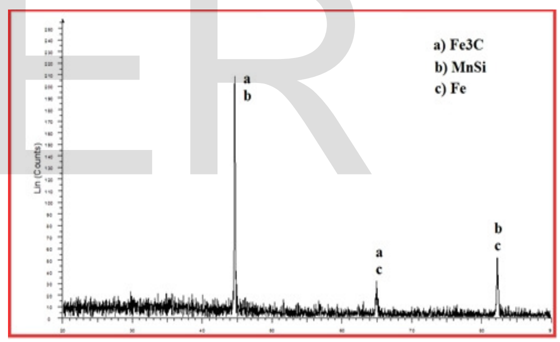

Fig. 9. The result of XRD analysis of sample no 4

4 CONCLUSION

1. St37- Optim 700 MC materials were successfully joined by using PTA welding method.
2. When the welded joints were examined in terms of penetration, full penetration was achieved in the joints weldedat 120A.
3. When the microstructure images of the welded joints were examined, microstructures of OPTIM 700 MC and St37 steels contained ferrite and perlite phases. When the joints made in the steel pairs with different welding power were examined in terms of metallographic aspect, it was observed that the welding seam had a homogeneous appearance and the penetration increaseddepending on the applied welding power.

4. When the tensile test results of the welded joints were investigated, the best joining value was obtained from the sample joined at 120 A with 520.176 MPa tensile value taken from the conducted joints according to the principle of that the sample having the values closest to the weldless standard sample among the samples subjected to tensile stress has the best joining value.
5. When the hardness results of the welded joints were examined, it was observed that the hardness value in HAZ increased compared to St37 and OPTIM 700 MC base material. This was thought to be caused by hard and brittle intermetallic phases forming in the weld zone of St37 – OPTIM 700 MC samples.
6. When the fracture surface and SEM images of the materials were examined, ductile fracture mechanism was observed to occur. Lack of brittle and hard intermetallic phases also supported this situation.
7. When EDS analysis of the materials was examined, ferrite and perlite phases were detected in St37 and OPTIM 700 MC steels. After XRD analysis, Fe3C and Fe phases were determined in structure of St37-St37 steel, on the other hand, Mn5Si2, Mn Si, Fe3C and Fe phases were determined in the structure of OPTIM 700 MC steel.

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