Examination Of Mechanical Properties And Weld Zone Of X70 Pipe Steel After Welding

Zakir Tas

Abstract: The demand for large diameter pipes in terms of their strength and toughness properties is increasing day by day. The quality and mechanical strength values of the steels, used in new gas pipeline projects, are gradually increasing. Today, high strength steels are used instead of the steels with low yield values. In this study, the micro-structure mechanical properties of the high strength X70 steel, used in the Trans Anatolian Gas Pipeline Project (TANAP), were investigated before and after the welding process and the weld zone was examined. The submerger arc welding process has been employed for the weld process. While the mechanical properties were determined by tensile, notched bend impact, bend and hardness measurements, the microstructures were examined by using optical microscope and scanning electron microscope (SEM). The radiographic and ultrasonic methods were employed in the non-destructive test of the weld zone.

Index Terms: mechanical properties, micro alloy, pipeline, weldability, submerger arc welding, high strength steels, weld zone, microstructure

1 Introduction

The gas transportation has become a primary industry, as the use of gas and oil transportation have become widespread. Not only the safety and cost, but also the production and installation of the materials used in this transportation made through large diameter pipes from long distances under high pressure conditions have attracted the attention. Therefore, the production of large diameter welded pipes, manufactured from flat products, has increased around the world. In addition to the properties of high strength and toughness, the good weldability properties of these pipes are requested. To improve the weldability, the group of low-pearlite steels is formed as the carbon ratio is decreased, also the toughness gain is achieved. The significant increase in toughness is enabled by modern metallurgical measures. The steels with high toughness can be produced by decreasing the sulphur ratio. Finally, the opportunity to improve the properties of pipe steels is utilized by employing thermomechanical rolling process [1]. The fairly high toughness properties are required in both pipe body and welding seam at low temperatures in particular for the safety of pipeline. The durability of pipeline under high pressure is not only based on the wall thickness of the pipe and the structure of material, but also the quality of welding seam [2]. In the production of pipe, it is aimed that the mechanical properties of welded zone and other zones are the same [3]. The quality and mechanical strength values of the steels, used in new natural gas pipeline projects, are gradually increasing. Today, high stress X70 or X80 steel technologies are used instead of the steels with low yield values such as X52 and X60 [4]. In this study, the micro-structure mechanical properties of the high strength X70 steel, used in the Trans Anatolian Natural Gas Pipeline Project (TANAP), were investigated before and after the welding process and the weld zone was examined.

2 Material and Method

For the pipeline weld of high quality, it is important to select the welding process, steel type and welding consumables, which are suitable for this steel, properly [5].

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API 5L PSL2 X70 fine-grained micro-alloyed steel materials with a thickness of 20 mm, which were and produced by using thermomechanical rolling process in accordance with API Standards, were used in this study. Table 1 shows the chemical composition of this material. The welding process was carried out by using submerger arc welding process in the factory of Noksel Çelik Boru A.Ş. (Noksel Steel Pipe Inc.) located at Iskenderun within the scope of the parameters given in Table 2. S2Mo welding wire and P223 welding power have been used in the joint welded by using automatic submerger arc welding machine. Table 3 and 4 shows the chemical compositions of the welding wire and powder.

TABLE 1
CHEMICAL ANALYSIS OF THE MATERIAL (WT.-%)

C	Si	Mn	P	S	Cu	Ni
.0707	.234	1.654	.006	.002	.029	.010
Cr	Al	Nb	V	Tİ	N	B
.169	.038	.057	.054	.020	.0022	.0002

TABLE 2
WELD PARAMETERS

	Current (A)		Voltage (V)		Wire Diameter (mm)		Welding Speed (cm/min)
	DC	AC	DC	AC	DC	AC	
Inside	1070	530	30	31	4	3.2	121
Outside	1140	550	30	34,5	4	3.2	121

TABLE 3
CHEMICAL ANALYSIS OF WELDING WIRE (WT.-%)

	C	Mn	Si	P	S	Mo	Cu*
S2Mo	0,05	0,95	0,2	0,025	0,025	0,45	< 0,35

**) Including the copper coating*

TABLE 4
CHEMICAL ANALYSIS OF WELDING POWDER (WT.-%)

	Al_2O_3	CaF2	Al2O3 + CaO + MgO
P 223	21	24	48

After the visual inspection was carried out for the welded samples, the radiographic and ultrasonic tests were carried out for these samples. Also, macroscopic images of them were taken. Two tensile test specimens, one from base material and one from weld zone were taken. The tests were carried out in Zwick/Roell branded tensile device in test speed of 1 mm/min. at room temperature. Three samples were taken from base material, HAZ and welding seam for the notched bend impact tests and it was prepared by making V-shape notch. The tests were carried out in Zwick/Roell type device at -15^{o}C. The hardness measurements were performed in Zwick/Roell device such a way to involve the base material, HAZ, and weld metal. The measurements were carried out by applying a load of 98 N in HV10. Two bend samples, as one face sample and one root sample, were prepared. The tests were carried out in the bend rate of 20 mm/min at room temperature. Being sanded by 320, 500, 800 and 1200 abrasives; the samples taken for the microstructure images were polished by paste of 1 μm and etched by 3% nital. The microstructure images of the samples were taken by using the optical microscope. The weld zones of the steels were examined in Joel branded SEM.

3 Test Results and Discussion

While visual inspection was carried out to determine surface defects of the joints welded by using submerger arc welding method; the radiographic and ultrasonic examinations were performed to determine the subsurface defects. As a result of the visual inspection and examination carried out on the macroscopic image (Figure 1); the weld defects such as crack, insufficient penetration, etc. were not observed on the weld surface.

Fig. 1. *Macroscopic image*

Radiographic examination was performed on samples and the defects which may occur on the weld zone were examined and accepted under the norms. The radiographic examination of the welded joints applied in the pipelines is one of commonly employed non-destructive test methods. The radiographic and ultrasonic examinations of the weld zone were performed and evaluated by an expert. Figure 2 shows the images of radiographic and ultrasonic examinations of the examined weld zone on the study screen.

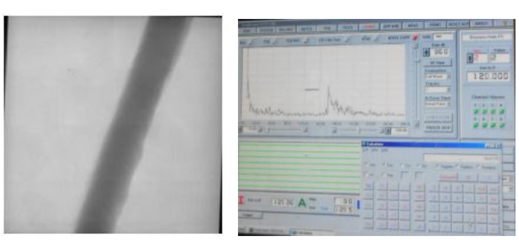


Fig. 2. *Images of a) radiographic, b) ultrasonic examinations of the weld zone on the study screen.*

The rupture in the welded samples as a result of tensile test occurred outside the weld zone, i.e. in base materials (Figure 3). Table 5 shows the strength and elongation (%) values obtained from the tensile tests.

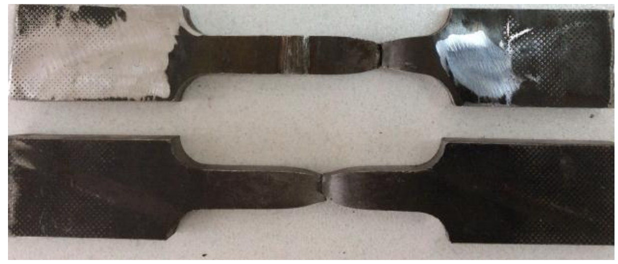


Fig. 3. *Tensile samples.*

TABLE 5

VALUES OF YIELD, TENSILE AND % ELONGATION.

Spec. Loc.	$R_{t0,5}$ (MPa)	R_m (MPa)	(%) Elongation
Material	536	669	27,5
Weld	630	735	18.4

When Table 5 was examined; it was found that tensile strengths of base material and welded sample were 669 MPa and 735 MPa, respectively, and the elongation values (in %) of the base material and welded material were 27.5% and 18.4%. It was observed that tensile values of the welded samples were higher than the tensile values of the base material. Even though the rupture occurred in the base material, the elongation values (in %) of the welded samples were lower. This is because no deformation occurred in the welded zone during tensile test [6]. The higher heat-flow occurs in the submerger arc welding process compared to other welding processes. High heat-flow in turn causes an increase in the hardness of material. As both hardness and tensile strength indicate the resistance of metals against the plastic deformation, these two values are roughly proportional. In other words; the rupture was caused by the base material with lower hardness instead of the weld metal or HAZ which confirms this result [7]. It was observed that the resistance of weld zone against the deformation resulted in an increase in tensile strength and a decrease in the elongation value (in %). In addition to the additional micro-alloy elements, all of the fine grain steels, depending on their producers, contain Mn to increase the yield point and strength. Ni is mostly added to improve the toughness of notched bend impact at low temperatures other than Mn. The yield point is increased by adding the limited ratio of Cu in proportion to Ni ratio without leading to disadvantageous results for the toughness of notched bend impact and weldability [8].

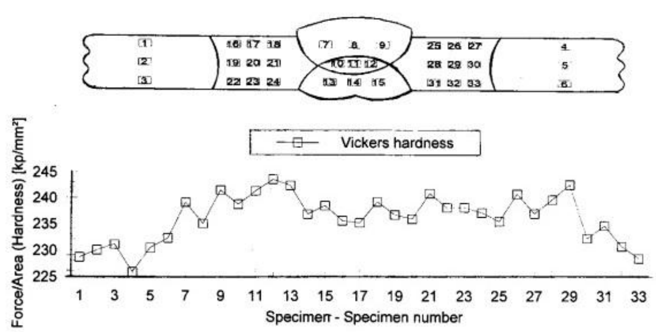


Fig. 4. *Distribution of hardness*

Hardness measurements during hardness test were performed on the points specified in Figure 4 in HV10. The hardness values are also given as graphics in Figure 4. When the graphic was examined, it was observed that the hardness of the weld zone was higher than the hardness of HAZ and base material. On the other hand, the hardness values measured in HAZ were found to be higher than compared to base material. While the highest hardness value was measured as 224 HV in the welding seam, it was measured as 243 in HAZ. The reason behind why the hardness value measured in HAZ was higher than those measured in the base material was the grain coarsening. In a study conducted in the weld zone of low carbon steel materials, it was specified that the hardness of HAZ was lower than weld metal [9]. The strength and hardness values of the weld zone are generally higher than those of base material. Its reason is that dislocation density of the welding seam and cooling rate during the welding are very high [10]. Bend test is not frequently used for the material examination. The weld examination is an exception [11]. The guided bend test was performed during the bend test and it was observed in face bend and root bend tests that defects such as rupture, cracks, etc. did not occur both in the welding seam and its surrounding (Figure 5). Thus, it can be concluded that the welding process was carried out properly and can be used easily under service conditions.

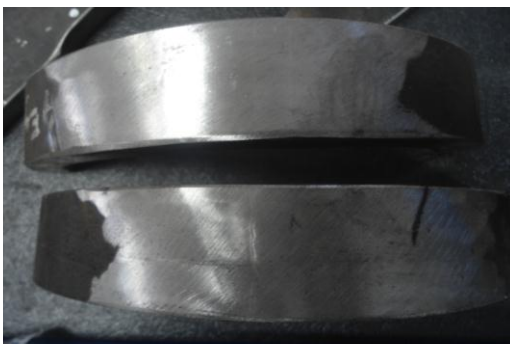


Fig. 5. *Bend samples*

The notched bend impact test was performed to determine the toughness values of samples. Table 6 shows the averages of the results obtained from tests. It is known that as the temperature decreases, the values of notched bend impact deteriorates.

TABLE 6

RESULTS OF NOTCHED BEND IMPACT TEST

a_k (J/mm^2)	Material	4,85
	Weld	1,78
	HAZ	2,14

The mechanical properties of a welded joint are affected by the mechanical properties of the agglomerated weld metal and the adjacent base metal (HAZ) affected by the heat treatment of the weld. Therefore, it is necessary to prevent the decrease in toughness and cracks which may occur both in the weld metal and HAZ after the welding [12]. In a previous study, it was specified that the toughness of HAZ was higher compared to the weld metal [13]. This result was confirmed by the fact that toughness of the notched bend impact of the HAZ was higher compared to the weld metal. In a study; Ti was suggested to improve the toughness [14]; on the other hand, another study revealed that Al and Ti have negative effects on the toughness [15]. Nitrogen and boron tend to form boron nitride compounds (BN) [16]. These boron nitrides may lead to deterioration of the toughness [17].

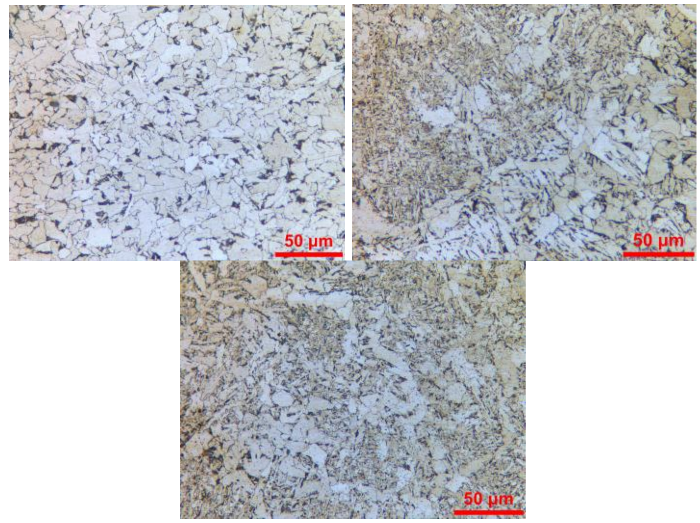
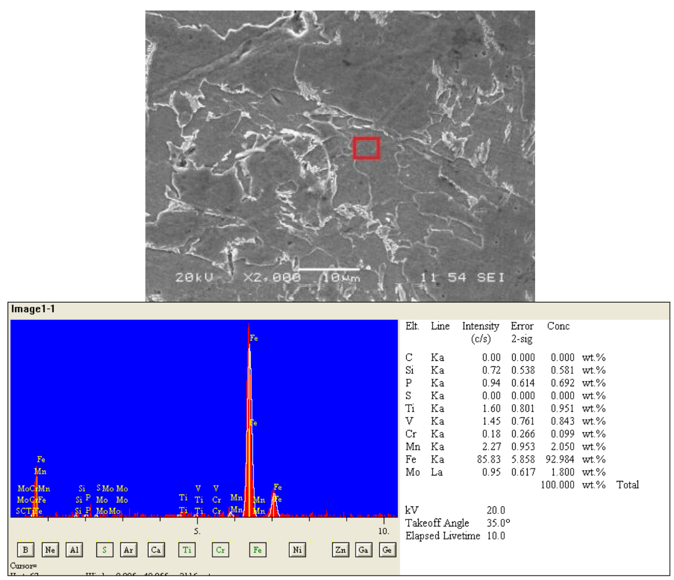


Fig. 6. *Optical microscopic images of a) base metal, b) HAZ, and c) weld metal.*

In addition to Al, N and B which are present in the chemical composition of the base material; it could be concluded that Ti was effective in the deterioration of the toughness of both HAZ and welding seam, as can be seen in EDS analysis (Figure 7). While Figure 6 shows the images of optical microscope taken from the base metal, HAZ and weld zone, Figure 7 shows SEM images and EDX analyses of the weld zone. The material was thermomechanically rolled and composed of fine grain ferritic microstructure. Microstructures partially contains pearlite and has a remarkable ferrite phase. It can be easily seen in the image of transition zone that grain structure of the weld zone was larger compared to the base material.



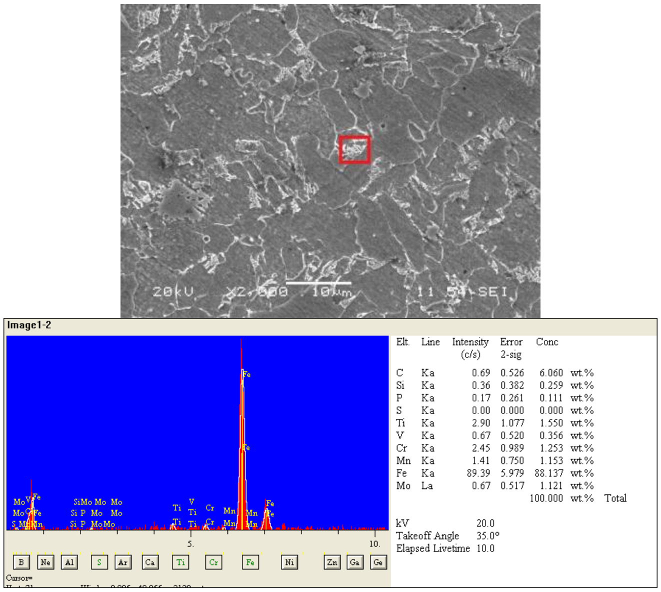


Fig. 7. *SEM images and EDS analyses of HAZ (a,b) and Weld Zone (c,d)*

Base material was composed of coaxial polygonal ferrite and pearlite islets. Micro-structure of fine and coarse grain HAZ was composed of grain boundary ferrite and Widmanstaetten ferrite. Microstructure of the weld metal was composed of polygonal and acicular ferrite. The formation of martensite structure is not desired in the weld zone since it will decrease the toughness. The very low ratio of carbon in the chemical composition of the steel and in the welding consumables used decreased the possibility of the formation of martensite. Therefore, the martensite structure did not form in the weld zone. The ferrite, showing various complex appearance, is formed by heterogeneous nucleation in the grain boundaries and around the inclusions in particular. The structure of the weld zone is generally a mixture of the primary (grain boundary ferrite, polygonal ferrite) and Widmanstaetten ferrite. The grain size significantly affects the mechanical properties of the weld zone. However, the toughness of weld zone is not safely associated with the grain size. As toughness affects the ferrite morphology (Widmanstaetten, acicular ferrite and grain boundary ferrite) and distribution of carbide [10].

4 Conclusions

- It was observed in the macrostructure examination that there was no misalignment between interior and exterior welds on the weld zone and no weld defects were observed. It was found in the microstructure examination that base material had fine-grain ferritic structure and there were pearlite islets between them.
- No problem occurred in the weldability of steel due to low ratio of C.
- As a result of tensile test, the tensile samples ruptured from the base material, not the weld zone, so the weld was found to be acceptable.
- The highest hardness values were measured in the welding seam, HAZ, and base material, respectively; on the other hand, the highest toughness values were determined in the base material, HAZ, and welding seam on the contrary. The micro-structure of the welded zone formed as a mixture composed of grain boundary, acicular, polygonal and Widmanstaetten ferrites.
- It was determined that tensile and hardness values of the weld metal increased compared to the main material, on the other hand, the toughness value decreased.
- The guided bend test was applied to the welded samples on the face and root sides and no defects such as crack, rupture, etc. were observed. Thus, it was concluded that the welding process was carried out properly.

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