

Effect of Nickel on the Microstructure, Hardness and Impact Toughness of SM570-TMC Weld Metals

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Abstract. SM570-TMC steel was applied in the various fields of steel construction where higher strength is required than conventional mild steel. This steel is commonly fabricated by fusion welding where flux-cored arc welding (FCAW) is preferred due to efficiency consideration. In this study, 14 mm thickness of SM570-TMC steel was butt weld by FCAW using three electrode wires with different nickel content (0% Ni, 1% Ni, 1.5% Ni). The microstructure of weldments was studied using an optical microscope. The hardness distribution tests were performed in the heat affected zone, parent metal and weld metal. And impact toughness of weld metals were measured at temperatures of 25 °C, 0 °C and -20 °C. The results show the steel plate welded using welding wire containing 1% Ni provides more superior impact toughness in the weld metal than welding wire 0% Ni, while the impact toughness of the sample which welded using welding wire containing 1.5% Ni tend to decrease. Nickel element which deposited to weld metal by using welding wires containing 1% Ni has improved the impact toughness, but 1.5% Ni may too high which deteriorate impact toughness. **Keywords:** Flux-cored arc welding (FCAW), SM570-TMC steel, microstructure, hardness, impact toughness, weld metal

1 Introduction

SM570-TMC steel is thermomechanically controlled processing (TMCP) product to improve the mechanical properties. This steel has a good strength, toughness, and weldability due to lower carbon equivalent than conventional steel [1]. SM570-TMC steel is nowadays applied in a various product of steel construction, e.g., bridges, ships, and other constructions where higher strength is required than conventional mild steel. This steel is currently used as steel construction of elevated toll in West Java, Indonesia.

The TMCP involves high temperature recrystallization-controlled rolling to produce a material with excellent characteristics by controlling the temperature of deformation during the hot-rolling processes [2,3]. TMCP of steel is an improving method for increase the mechanical properties (strength, toughness, and ductility) through the grain refining microstructure on transformation [2,4,5]. TMCP is a process that integrated work hardening and heat treatment into a single process which has transformed steelmaking into effective, efficient, high quality and sophisticated manufacturing industry [5].

Selection of fusion welding method influences the impact toughness of this steel welds. The oxidation influence of shielding gas which used in the gas metal arc welding (GMAW) deteriorate the impact toughness of weld metal [6]. R. Pamnani et al. found the submerged arc welding (SAW) method resulted the lowest impact toughness of weld metal compare to shielded metal arc welding (SMAW) and FCAW due to produce more number of inclusions [7].

FCAW is fusion welding which commonly used in the fabrication of SM570-TMC steel considering the efficiency and cost-effective. However, there are various factors to be considered for the performance of welding joint concern, e.g., welding parameters, welding wires, shielding gas, etc.

The impact toughness of weld metals was influenced by elements composition, grain size, phase structure of the boundary and inclusion amount [7]. Microstructures of weld metals are also influenced by the kind of gases of the shielding gas used (O₂ and CO₂ content) [8,9]. H.K. Sung et al. found a fraction of acicular ferrite in API X80 steel will increase by increasing amount of oxides and then decreased by increasing heat input [10]. The impact toughness of steel weld is higher due to the refined microstructure and high percentage of acicular ferrite in steel weld [7,11].

The impact toughness of the steel weld in fusion welding was directly proportional to the nickel content in the weld metal [7,11]. Mechanical strength and impact toughness of weld metal are improved by increasing nickel percentage due to this element contributed to the presence of acicular ferrite [11,12,13]. Nickel offers benefit as an alloying element to produce high strength steels. However, in the oil and gas industry, nickel content is limited to a maximum of 1 wt% considering crack resistance concerns [13]. Nickel improves the toughness when it is added alone when nickel was co-present with a high amount of manganese; nickel affects mechanical properties in complicated ways because the microstructure became martensite which susceptible predominantly to intergranular brittle crack propagation [11].

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This study objection was to investigate the effect of nickel to impact toughness of SM570-TMC steel weldment by employing FCAW method using flux-cored wires with three different nickel content (0% Ni, 1% Ni, 1.5% Ni). The impact toughness of weld metal was performed at temperatures of 25 °C, 0 °C, and -20 °C.

2 Research Procedure

2.1 Material and Welding Procedures

The parent metal employed in this welding experiment was 14 mm thickness SM570-TMC steel plate supplied by PT Krakatau Posco, Indonesia. Chemical composition analysis of the SM570-TMC test plate is represented in Table 1. Use A4 paper size (210 x 297 mm) and adjust the margins to those shown in Table 1.

Table 1. The elements composition and mechanical properties of the SM570TMC

Base metal	C	Mn	P	S	Si
SM570-TMC	0.156	1.487	0.011	0.002	0.498

Base metal	Yield strength (MPa)	UTS (MPa)	Elongation (%)
SM570-TMC	0.156	1.487	0.011

Table 2. The chemical composition of welding wire(wt.%)

Base metal	C	Mn	P	S	Si	Ni
K71T	0.04	1.25	0.015	0.011	0.55	0
81-Ni1	0.05	1.15			0.34	0.96
81-K2	0.04	1.2	0.012	0.01	0.38	1.58

The SM570-TMC test plates were cut to the dimensions of 175 × 125 × 14 mm, and then V-groove joint design with an angle of 45° was prepared for butt joint as shown in Figure 1. The multi-pass welds with the flat position (1G) were performed using FCAW method and shielding gas 99.9% CO₂. The welding procedure refers to AWS D1.5 for Bridge Welding Code standard.

Three SM570-TMC steel plates were flux-cored arc welded by varying the welding wire type which has different nickel content. 1.2 mm diameter of welding wires used in this welding experiment were K71T (0% Ni), 81Ni1 (1% Ni), and 81K2 (1.5% Ni). The welded plate samples are referred to as WM-0Ni, WM-1Ni, and WM-1.5Ni according to the amount of nickel in the welding wire.

The elements composition of these flux-cored electrodes were shown in Table 2. The preheat temperature of 50 °C minimum was applied before the welding experiments started, and the interpass temperature of 150 °C maximum was maintained. The welding experiments were carried out in seven passes with welding current 200 A, voltage 25.5 V, and an average welding speed of 270 mm/min. Hence, heat

input was calculated become 1.1. kJ/mm based on this welding parameter (Table 3).

Table 3. Welding parameters used in the experiments

Specimen	No of run	Welding parameter			
		Current (A)	Voltage (V)	Travel speed (mm/min)	Heat input (kJ/mm)
WM-0Ni	1	200	25.5	270	1.1
	2	200	25.5	270	1.1
	3	200	25.5	270	1.1
	4	200	25.5	270	1.1
	5	200	25.5	270	1.1
	6	200	25.5	270	1.1
	7	200	25.5	270	1.1
WM-0.96Ni	1	200	25.5	270	1.1
	2	200	25.5	270	1.1
	3	200	25.5	270	1.1
	4	200	25.5	270	1.1
	5	200	25.5	270	1.1
	6	200	25.5	270	1.1
	7	200	25.5	270	1.1
WM-1.58Ni	1	200	25.5	270	1.1
	2	200	25.5	270	1.1
	3	200	25.5	270	1.1
	4	200	25.5	270	1.1
	5	200	25.5	270	1.1
	6	200	25.5	270	1.1
	7	200	25.5	270	1.1

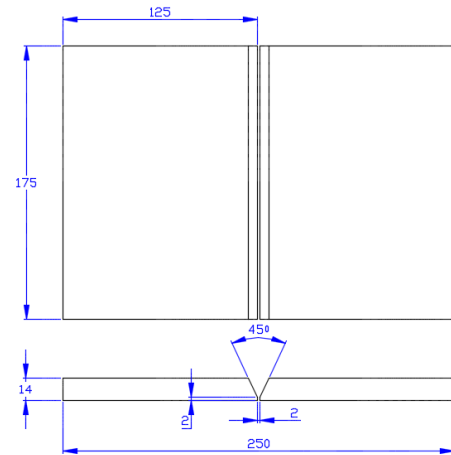


Fig. 1. Welded plate geometry and dimensions



Fig. 2. SM570-TMC steel plates after welding

2.2 Microstructural Analysis

For the microstructure analysis purpose of welded plates, the welded specimens were cut transversally to the welding direction. Metallographic examinations were performed after polishing and then etching using 3% nital. Optical microscope Leica DM 1750M with 500× magnification is used to observe microstructure evolutions after the welding process.

2.3 Hardness and Charpy Impact Test

The hardness and Charpy impact test specimens were prepared for mechanical properties investigation. The specimens were cut across the welding direction as shown in Figure 3.

Hardness test was performed at room temperature (25 °C) by using the Futuretech FV-310 machine with a load of 10 kgf for 15 seconds. The hardness tests were performed in three different zones: weld metal (WM), heat affected zone (HAZ), and base metal (BM).

The specimens of Charpy impact test were prepared according to ASTM E23 in the dimensions of 55 × 10 × 10 mm Charpy V-notch specimens. Charpy impact test was carried out using Tinius Olsen Impact Tester 542J machine with a maximum capacity of 542 J. Charpy impact test was performed at test temperatures of 25 °C, 0 °C, and -20 °C. For the low temperatures test purpose, the test specimens were immersed in the liquid cooling media of nitrogen + methanol until reaching the specified temperature.

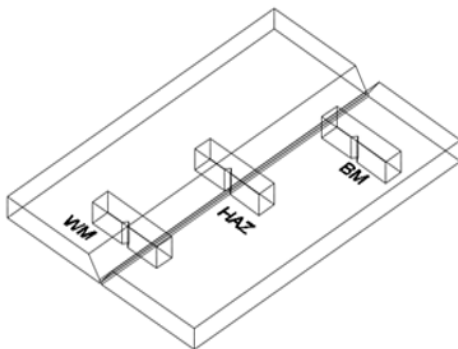


Fig. 3. Notch location of the specimens

3 Results and Discussion

3.1 Microstructure Analysis

The microstructure observation was performed by using the optical microscope with 500× magnification. Representative optical microscope observation of base metal is shown in Figure 4. The optical micrographs of three weld metals as resulted by welding wire with different nickel content are shown in Figure 5. Effect of nickel then can be analyzed through microstructure changes.

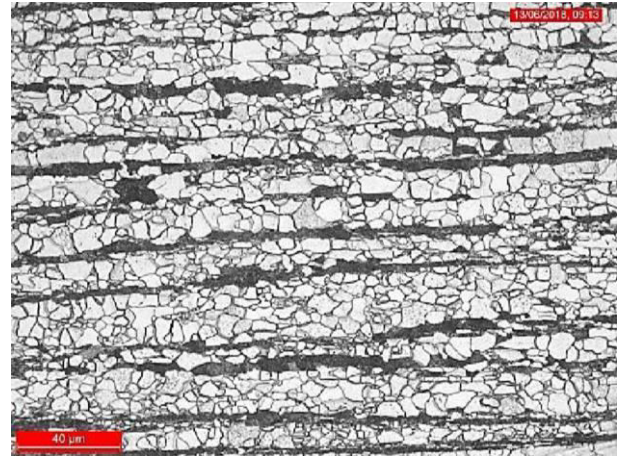
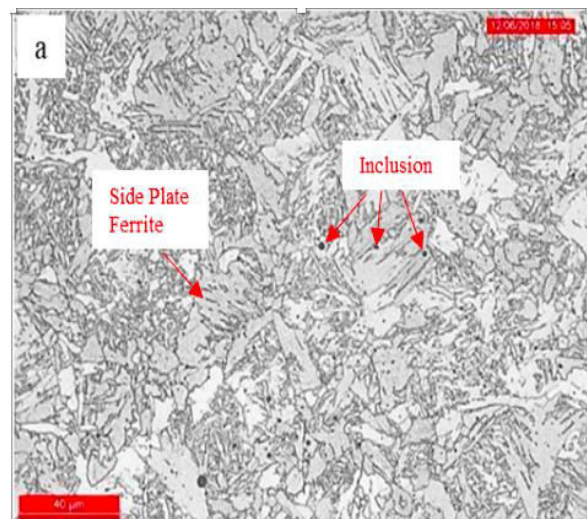


Fig. 4. Metallographic photograph of an SM570-TMC base metal

It can be seen in Figure 5b that the weld metal of specimen WM-1Ni (using welding wire 1%Ni) consisted mainly of acicular ferrite. Nickel contributes to stabilize the austenite grains and decreased the temperature of ferrite transformation, hence promotes acicular ferrite, while the formation of side plate ferrite and grain boundary ferrite were suppressed significantly [12]. Acicular ferrite contributes to improving low-temperature impact toughness.

The microstructure of weld metal specimen WM-0Ni (using welding wire 0% Ni) has side plate ferrite (Figure 5a). The weld metal specimen WM-1.5Ni (using welding wire 1.5% Ni) shows coarse grains with grain boundary ferrite (Figure 5c).

Some amount of inclusions was found in all three specimens of weld metals (WM-0Ni, WM-1Ni, WM-1.5Ni). The inclusions may include the oxides due to 99.9% CO₂ as the shielding gas was used during the welding operation.



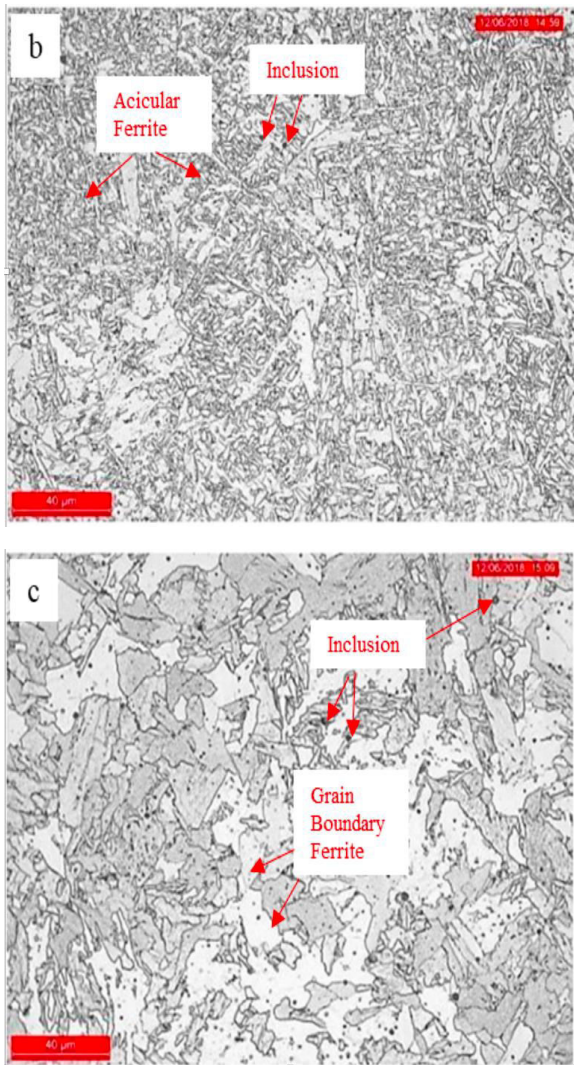


Fig. 5. Metallographic photographs of SM570-TMC weld metal : (a) WM-0Ni, (b) WM-1Ni, (c) WM-1.5Ni

3.2 Hardness Test Results

The hardness distribution across SM570-TMC weldments have been measured as shown in Figure 6. Hardness test result of the base metal is in range of 175-200 HV. The highest hardness found in HAZ for both specimens WM-0Ni (280 HV) and WM-1Ni (223 HV) while the hardness of specimen WM-1.5 Ni has not significantly different between HAZ and weld metal (Figure 7). This result is comparable with the result of Winarto et al. [14] who observed the highest hardness in HAZ (382-431 HV) compared to weld metal and base metal for the HY80 weldment.

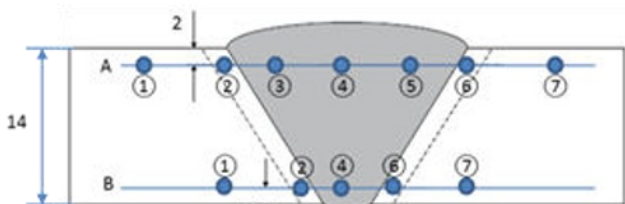


Fig. 6. Indentation of hardness distribution test on a cross-section of SM570-TMC weld metal

The hardness at the center of weld metal WM-1Ni (172-191 HV) is the lowest compared to WM-0Ni (186-214 HV) and WM-1.5Ni (206-216 HV) which correspondence to containing some amount of acicular ferrite (Figure 5b). And the hardness of the weld metal of WM-1.5Ni is the highest due to coarser grains as shown in Figure 5c.

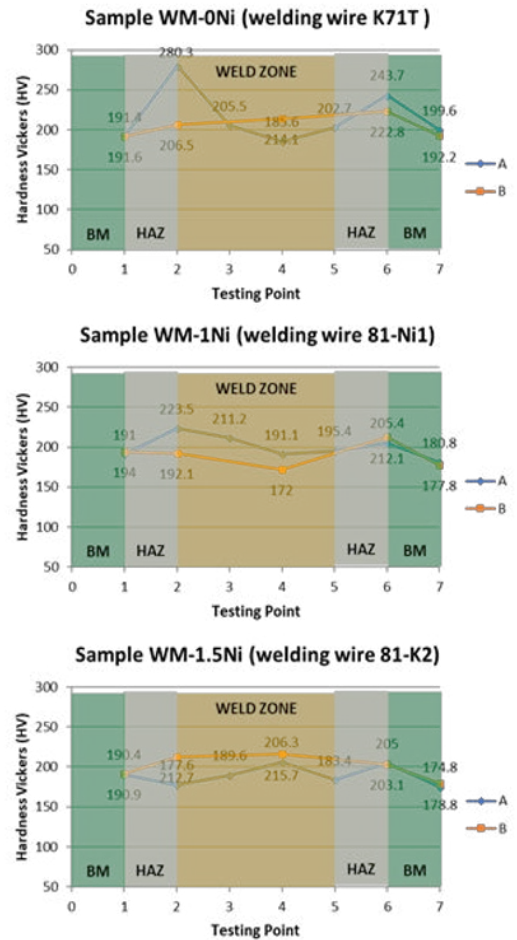


Fig. 7. Hardness distribution of three SM570-TMC weldments : WM-0Ni (0% Ni), WM-1Ni (1% Ni), WM-1.5Ni (1.5% Ni)

3.3 Impact Toughness Properties

Charpy impact test of weld metal and base metal was tested twice per test temperatures. The results indicated that test temperatures and nickel content of welding wire had influenced the impact toughness of weld metal.

Weld metal WM-0Ni (0% Ni) has the lowest impact toughness compared to WM-1Ni (1% Ni) and WM-1.5 Ni (1.5% Ni). It caused during welding operation there was no nickel element to be deposited to weld metal from welding wire used. The metallographic photographs show the side plate ferrite.

Weld metal WM-1Ni has much higher impact toughness than WM-0Ni due to the presence of acicular ferrite. Nickel which was deposited to weld metal from welding wire 1% Ni contributed to stabilizing the austenite grains and decreased the temperature of ferrite transformation, hence promotes acicular ferrite,

But, when nickel content is in a higher level as used for specimen WM-1.5Ni, the impact toughness tend to decrease. It might be attributed to the microstructure evolution during welding operation, coarser grains were found in microstructure observation (Figure 5c). Nickel content in the welding wire 1.5% Ni used for specimen WM-1.5Ni may too high where the hard phases formation started. It compares with the previous study by B.Y. Kang et al. [11] who found a large addition of nickel at 1.6% manganese was seriously reduced the impact toughness. In the previous study, microstructure became martensite predominantly when nickel was present with a higher level of manganese [11].

Table 4. Charpy impact toughness of SM570-TMC steel welds at test temperatures of 25 °C, 0 °C, -20 °C

a) WM-0Ni (0% Ni)			
Test temperature (°C)	-20	0	25
Impact toughness (J)	68	99	140

b) WM-1Ni (1% Ni)			
Test temperature (°C)	-20	0	25
Impact toughness (J)	153	168	185

c) WM-1.5Ni (1.5% Ni)			
Test temperature (°C)	-20	0	25
Impact toughness (J)	108	134	147

d) BM (base metal)			
Test temperature (°C)	-20	0	25
Impact toughness (J)	289	310	299

It could be found that the impact toughness of all weld metals WM-0Ni, WM-1Ni, and WM-1.5Ni decreased with decreasing of test temperatures from the temperature of 25 °C to -20 °C. At a temperature of 25 °C, the impact toughness of weld metals are 140 J (WM-0Ni), 185 J (WM-1Ni), and 147 J (WM-1.5Ni). Then the impact toughness decreased at a temperature of -20 °C became 68 J (WM-0Ni), 153 J (WM-1Ni), and 108 J (WM-1.5Ni) as presented in Figure 8.

The impact toughness of weld metal WM-0Ni drastically drops (49%) when temperature decreased from 25 °C to -20 °C due to in absence of nickel element which transferred from welding wire. At same condition, impact toughness of weld metal WM-1Ni and WM-1.5 Ni reduced 83% and 73%, respectively.

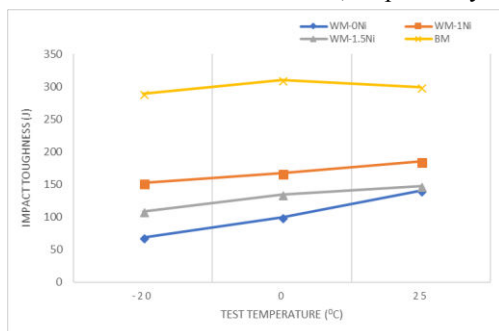


Fig. 8. Impact toughness of base metal (BM) and three specimens of weld metals (WM-0Ni, WM-1Ni, WM-1.5Ni) as a function of test temperatures

4 Conclusions

Effect of nickel content of welding wire on the microstructure, hardness, and impact toughness of weld metals in SM570-TMC steel fabricated by FCAW has been investigated. It can be found that the weld metal of specimen WM-1Ni (using welding wire 1%Ni) consisted mainly of acicular ferrite which may contribute to improving the impact toughness significantly compared to 0% Ni. But, the impact toughness tends to decrease by using welding wire containing 1.5% Ni. It seems 1.5% nickel content is too high due to contributed to form hard phases and coarser grains that deteriorate the impact toughness. For all specimens (WM-0Ni, WM-1Ni, WM-1.5Ni), impact toughness of weld metals decreased when the temperature decreased from 25 °C to -20 °C. Impact toughness of specimen WM-0Ni which has no nickel to be deposited into the weld metal had drastically dropped (49%) when temperature decreased from 25 °C to -20 °C.

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