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COMPARISON OF NON-DESTRUCTIVE AND DESTRUCTIVE WELDING ASSESSMENT TESTS ON MAG-WELDED AISI316L AND DH36 STEELS USING K-309LT FILLER

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Abstract
This study provides a comparative analysis of non-destructive testing (NDT) and destructive testing (DT) applied to MAG welding of dissimilar AISI316L and DH36 steels using K-309LT filler wire. The welding process, performed in vertical and horizontal positions on a ceramic support, was optimized for mechanical integrity. NDT techniques such as ultrasonic, visual and penetrant testing, enabled the detection of internal and superficial defects such as porosity, lack of fusion and cracks without affecting the test samples. However, they did not provide information on mechanical performance under load. DT methods, including tensile, impact, bending and hardness tests, provided critical data on weld structural integrity, toughness, ductility and the effects of heat input on the microstructure, particularly in the fusion and heat-affected zones. These destructive tests confirmed the nature of the defects, detected, and assessed their impact on the performance of the weld. The study concludes that, while non-destructive testing is essential for preliminary quality control, it should be complemented by DT for a complete understanding of weld behavior under service load. The synergy of both approaches is crucial to ensure safety, durability and optimal performance of welded structures made of different steels.

Keywords: *MAG welding, AISI316L, DH36, K-309LT filler, non-destructive testing (NDT), destructive testing (DT), welding quality control*

1. INTRODUCTION

The field of welding and fabrication plays a crucial role in various industrial sectors, including manufacturing, construction, and shipbuilding. Welding parameters in industry significantly influence production quality [1], with proper selection of parameters, suitable material choice [2], and stable arc conditions and methods used in welding [3] being key factors for achieving optimal results. Among diverse welding processes, Metal Active Gas (MAG) welding has gained popularity due to its versatility and efficacy, particularly for thick section welding. This study focuses on the specific case of MAG welding involving two different grades of steel, AISI316L and DH36, using K-309LT filler [4]. Despite its wide usage, the integral question of weld quality assurance in this process remains a subject of considerable debate and investigation. Weld quality can be evaluated through various testing methods, broadly categorized as non-destructive testing (NDT) and destructive testing (DT). While NDT allows for the detection of defects without causing damage to the test piece, its inability to measure mechanical properties is a limitation. On the other hand, DT provides a comprehensive understanding of the mechanical and metallurgical properties of the weld but compromises the integrity of the test samples [5]. This paper aims to compare and contrast NDT and DT methods applied to the MAG welding process of AISI316L and DH36 steels using K-309LT filler. The objective is to highlight the strengths and limitations of each testing method and ascertain their optimum utilization for quality assurance in welding different grades of steel on this particular case. Through this comprehensive comparison, the study seeks to provide valuable insights that can enhance the efficiency, reliability, and service life of welded structures. The findings of this research will be highly beneficial for industries relying heavily on welding dissimilar steels, promoting safer and more efficient operations.

2. EXPERIMENTAL

Materials used in this research include two types of steel and one welding wire, with their chemical compositions presented in Table 1.

Table 1. Chemical composition comparison

Element (Fe Bal.)	AISI 316L (%)	DH 36 (%)	Kiswel K-309LT (%)
C	≤ 0.03	0.18	0.03
Si	≤ 1.0	0.50	0.4
Mn	≤ 2.0	1.6	1.2
P	≤ 0.045	0.035	0.03
S	≤ 0.03	0.035	0.03
Cr	16-18	0.20	23.7
Ni	10-14	0.40	13.2
Mo	2-2.5	0.08	-
N	≤ 0.1	-	-
Cu	-	0.35	-
Cb	-	0.05	-
V	-	0.10	-
FN	-	-	12

AISI 316L stainless steel (EN: X2CrNiMo18-14-3, material number 1.4435) belongs to the austenitic stainless steel group, commonly known as inox, prochrom, or marine steel. This steel typically contains 0.02–0.15% carbon, 16–24% chromium, 8–12% nickel, and can be alloyed with molybdenum, niobium, nitrogen, tantalum, and titanium. Its primary advantage is resistance to intergranular corrosion, while its drawback is reduced yield strength due to the low carbon content. DH 36 steel (EN 10025) belongs to high-strength shipbuilding steels, characterized by maintaining yield strength of at least 355 N/mm² even at -20 °C. It is distinguished by good weldability and machinability, owing to its low carbon content (0.18%). Due to these favorable mechanical characteristics, DH 36 steel is primarily used for constructing ship hulls. Unlike AISI 316L, DH 36 steel is not corrosion resistant and thus requires proper protective coatings to prevent corrosion. The welding filler material Kiswel K-309 LT is a flux-cored wire designed for MAG welding of similar and dissimilar stainless steels. It exhibits excellent weldability and allows welding in various positions using either 100% CO_2 or a gas mixture containing 82% Ar and 18% CO_2. This filler material provides deep penetration and excellent mechanical properties of the weld joints, especially when using a spray arc transfer mode. It is also employed for cladding purposes. The welded joint was prepared between two different steel types, AISI 316L and DH36, using the Kiswel K-309LT welding wire. Both steel plates, 25 mm thick, were beveled at a 45-degree angle, forming a "V" joint configuration suitable for welding in a vertical position. A ceramic backing strip was positioned on the backside of the joint to facilitate root pass welding and prevent melt-through. The welding parameters were meticulously selected according to the welding procedure specification (WPS), ensuring consistent quality across all passes. A total of 30 welding passes were applied, with inter-pass slag removal and surface grinding after each pass to maintain weld integrity. The inter-pass temperature was controlled not to exceed 150 °C. The weld quality was evaluated using non-destructive testing (NDT) techniques, including visual inspection, penetrant testing, and ultrasonic testing. Visual inspection identified surface defects, penetrant testing was applied to detect any surface-breaking discontinuities, and ultrasonic testing assessed internal defects within the welded joint. Destructive tests (DT) conducted included tensile testing, impact testing, bending tests, and hardness measurements. Tensile tests determined the ultimate tensile strength and ductility of the weld. Impact tests, performed using the Charpy impact method at 0

°C, assessed weld toughness. Bending tests were conducted from both root and face sides to evaluate the ductility and potential for cracking under bending stress. Hardness was measured using the Vickers method across the weld metal, heat-affected zone (HAZ), and base materials.

3. RESULTS AND DISCUSSION

Non-Destructive Testing (NDT)

Penetrant Testing

Penetrant testing was performed using TIEDE-PEN PWL-1 penetrant, DL-20 developer, and RL-40 surface cleaner. The surface was brushed and cleaned with water, at an ambient temperature of 20 °C. The penetrant dwell time was 20 minutes, with a developing time of 20 minutes. The examination was concluded with acceptable results.

Ultrasonic Testing

Ultrasonic testing was carried out using KRAUTKRAMER USN-52 equipment with probes MWB 60-4 MHz and MWB 70-4 MHz. The calibration block used was 1.2 mm, with a gauging range from 100 to 200 mm. Couplant ZG was used, and the sensitivity was rated as E1. The gain was set between 46-52 dB. The examination results were acceptable.

Visual Control

Visual control was conducted following standards HRN EN ISO 5817 and HRN EN 970, with a sandblasted surface condition. The examination indicated an acceptable result.

Visual inspection revealed uniform bead formation without significant surface defects. Penetrant testing did not show any surface discontinuities. Ultrasonic testing confirmed the absence of significant internal defects, indicating good weld integrity.

Destructive Testing (DT)

The hardness of the samples was measured using the ZHU 187.5 universal hardness tester with Vickers (HV 10) hardness pyramid indenter. In addition, all tensile and bending tests in this study were performed at room temperature using a universal tensile testing machine ZWICK Z/100.

Tension Testing

Results of tension test are seen in table 2. All samples failed outside the weld area, indicating satisfactory weld performance.

Table 2. Tension test of welded example

Sample No.	Cross-section (mm^2)	Force (F/N)	Tensile Strength (N/mm^2)	Yield Point (F/N)	Yield Limit (N/mm^2)	Elongation (mm)	Reduction of Area (%)
1	14.0 x 25.0	198800	568	140000	400	429	–
2	14.0 x 25.0	200500	573	141000	404	413	–
3	14.0 x 25.0	198000	566	140500	402	424	–
4	14.0 x 25.0	200000	571	141500	404	419	–

Impact Testing

Impact testing was performed at 25 °C on standard test size 10 mm x 10 mm x 55mm. Results showed on Table 3. have satisfactory toughness values, especially in the fusion zone.

Table 3. Impact dynamic testing results of welded example

Sample No.	Impact Toughness (J)	Position	Average Impact Toughness (J)
6	63	center weld	60.0
7	58	center weld	60.0
8	59	center weld	60.0
9	133	fusion zone	137.67
10	132	fusion zone	137.67
11	148	fusion zone	137.67
12	137	2 mm from fusion zone DH36	144.0
13	140	2 mm from fusion zone DH36	144.0
14	155	2 mm from fusion zone DH36	144.0

Banding Test

Results for three-point banding test are seen in Table 4. All bending tests passed, demonstrating good ductility and soundness of the weld.

Table 4. Bending test results of made samples from welding example

Sample No.	Dimensions (mm)	Diameter (mm)	Angle (°)	Test Type	Result
1	10 x 25	40	180	side bending	O.K.
2	10 x 25	40	180	side bending	O.K.
3	10 x 25	40	180	side bending	O.K.
4	10 x 25	40	180	side bending	O.K.

Hardness Test

Hardness testing was performed by Vickers hardness test, three locations were tested and micro locations on each sample are shown on Figure 1. The hardness values seen in Table 5. represent the average of five measurements with the standard deviation. The carburized layer was removed before the test. The hardness values obtained after welding are consistent with the data reported in the experimental literature of chosen steels [1-5].

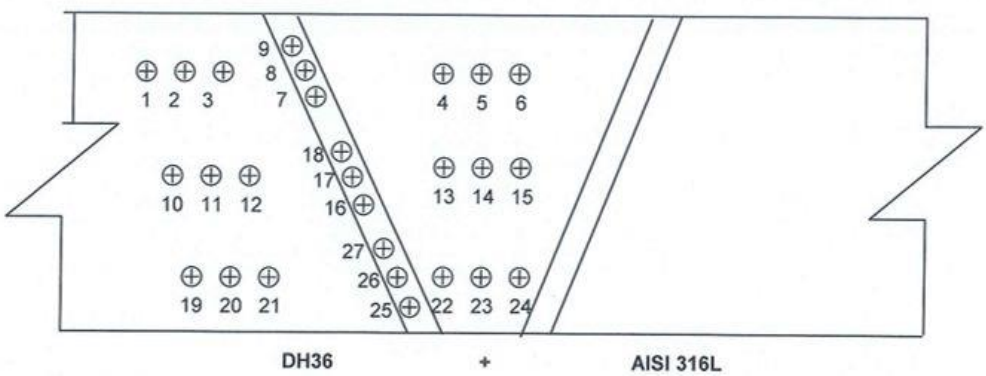

Figure 1. Positions of measure micro point locations for Vickers hardness test

The results of the destructive tests provided detailed data on the mechanical properties. Tensile tests confirmed satisfactory strength and ductility, with failures predominantly in the base metal, emphasizing the weld's excellent integrity. Impact tests demonstrated robust toughness, highlighting the weld's suitability for dynamic or low-temperature applications. Bending tests confirmed excellent ductility, with no cracking observed, indicating strong resistance to deformation.

Table 5. Hardness Vickers measurements of samples

Sample No. 1. (Upper side)		Sample No. 1. (Middle side)		Sample No. 1. (Lower side)	
Measure point	Results	Measure point	Results	Measure point	Results
1	202	10	176	19	171
2	185	11	170	20	178
3	206	12	187	21	197
4	253	13	272	22	285
5	250	14	272	23	264
6	243	15	274	24	274
7	250	16	245	25	272
8	289	17	319	26	242
9	300	18	270	27	274
HV 10 max.	350	HV 10 max.	350	HV 10 max.	350

The presented results demonstrate the effectiveness and complementarity of non-destructive testing (NDT) and destructive testing (DT) methods in assessing the quality of MAG welded joints between AISI 316L and DH36 steels using Kiswel K-309LT welding wire. NDT methods, including visual, penetrant, and ultrasonic testing, confirmed the absence of significant defects, indicating good preliminary weld quality. The DT provided comprehensive insight into mechanical properties, complementing NDT by validating weld integrity through mechanical performance data. Hardness profiles indicated appropriate heat management, reflected by gradual changes in hardness from the weld metal to the base metal. The synergy between NDT and DT emphasizes that integrating both test methods is essential for thorough quality control in practical welding applications. This study offers valuable insights into material behavior during MAG welding of AISI 316L and DH36 steels with K-309LT filler, underscoring the importance of scientific methodology and adherence to standards for achieving high-quality welded joints and maintaining professional standards in production practices.

4. CONCLUSION

This study has confirmed that MAG welding of dissimilar steels (AISI 316L and DH36) using Kiswel K-309LT filler wire can produce welds of excellent mechanical and structural integrity. Non-destructive testing methods effectively detected initial defects, while destructive testing enabled a comprehensive assessment of mechanical properties. The combination of both testing approaches is crucial to accurately determine weld quality, ensuring the reliability and durability of welded structures in real-world applications. Further study will be focused on the quality of the operator or welding machine, as well as the welding positions used in joining material plates, in order to ensure the final weld quality and meet the requirements set by the classification society Bureau Veritas.

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