Non-destructive test inspection of gas metal arc welding products with clamp and heat sink treatment on low carbon steel

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Abstract. Efforts to reduce the level of distortion by welding treatment need to be done, but must consider the quality of the weld, especially the weld joint area. This study aims to examine non-destructive test (NDT) on welded objects with clamp and heat sink treatment to determine the level of weld perfection and detect welding defects in order to ensure weld quality. This research was conducted with 4 welding treatment designs, include: as welded, 4-point clamp treatment (4Clamp), liquid nitrogen cooling (HS-N₂) heat sink treatment, and flowing water-cooling (HS-H₂O) heat sink treatment. The results showed that based on the visual test of the welding on as welded condition, 4-points clamp, and flowing water cooling heat sink treatment decided “accepted”, while the heat sink treatment with liquid nitrogen did not pass the test and decided “rejected”. The dye penetrant test results of the HS-N₂ treatment detected cracks at the end of the weld surface caused by a decreasing of heat input due to the HS-N₂ treatment.

1. Introduction

Welding treatments are used intensively in various manufacturing industries, such as: automotive, shipping, aircraft, trains, bridge construction, pressure vessels, etc. Welding treatments have various advantages for production such as cost savings, size accuracy, and variations in the shape of the weld structure. The welding treatments can cause detrimental effects, including: decreased strength and toughness of the material and resulting weld imperfections, such as cracks, defects, and porosity, which cause a decrease in the quality of the weld joint.

Factors that affect the quality of the weld start from welding planning, welding preparation, and procedures when welding and welding treatments. Welding treatments that are commonly used to reduce distortion levels are thermal and mechanical effects that have an impact on changes in heat input during welding [1]. The decreased heat input will cause a change in the appearance of the weld bead and the ability of weld penetration. This is because the small heat input will cause the metal melting energy to be smaller and result in the welding volume and the weld penetration getting smaller [2].

Welding inspection is carried out on post-welding construction to guarantee the quality of the welds and to provide a positive assessment of the construction to meet technical and economic requirements. One of the weld inspections is carried out by using the non-destructive test (NDT) test to detect the presence of cracks, slag (trapped slag), defects, porosity, and welding inclusions. Types of NDT testing that are commonly used to determine the damage/ defect both on the surface and inside of...
the weld include: a) visual test, b) penetration/penetrant test, c) magnetic particle test, d) electric current rotation test or known test Eddy current, e) radiographic test, and f) ultrasonic test.

NDT testing with radiography was carried out by Soembogo [3] on a pressure vessel manhole weld. Levesque [4] conducted an NDT test using an ultrasonic technique combined with a laser to detect defects in thick steel plates. Likewise, the use of a stereo vision camera for 3D visual detection was also developed by Bracun [5] to visually measure the parts on the weld, so that fast and accurate measurements can be carried out.

Referring to the fact that inspection of welding results is an important step that needs to be carried out after the welding process, this research needs to be carried out in particular with the application of the welding method. The research is focused on the non-destructive test (NDT) of welding results. The objectives of this study are: a) to determine the level of weld perfection through a visual test of the welding results using weld treatment of clamp method, liquid nitrogen heat sink method and water heat sink method, b) to determine the defects of the weld through the dye penetrant test, the results of the weld treatment with clamp method, liquid nitrogen heat sink method and water heat sink method.

2. Materials and method
2.1. Materials

This study uses A36 steel plate with a thickness of 4 mm as the base metal and electrode type ER70S-6 with a diameter of 0.8 mm is used as a filler in the welding process. The chemical composition of A36 steel and the ER70S-6 electrodes is shown in Table 1.

| Kompositi | C (%) | P (%) | S (%) | Si (%) | Cu (%) | Mn (%) |
|-----------|-------|-------|-------|--------|--------|--------|
| Low carbon steel A36 | max 0,25 | max 0,04 | max 0,05 | max 0,4 | max 0,2 | - |
| Electrode ER70S-6 | 0,10 | 0,11 | 0,12 | 0,88 | 0,24 | 1,56 |

2.2. Welding process

A36 steel plate with dimensions of 400 mm x 80 mm x 4 mm is joined using GMAW welding with a butt V joint, giving a 30 degree slope at both ends to be welded with a root pass of 1 - 2 mm. The workpiece is welded by GMAW welding which is operated automatically with the help of a welding rig equipment. The parameters for welding GMAW with 4 mm thick carbon steel using ER70S-6 electrodes with an electrode diameter of 0.8 mm, wire feed of 135 mm / second, and gas discharge of 5 liters / minute [8].

Both clamp and heat sink treatments are applied during the welding process. The clamp functions as a holder for the workpiece to be placed at the end of both sides of the weld workpiece so that it does not change shape. The heat sink functions as a heat sink which is placed on both sides of the welding line which is 10 mm from the center of the weld. The heat sink has 2 variations, namely heat sink with liquid nitrogen media and heat sink with running water media.

This research was conducted with the following design:
1) Design 1: without welding treatment (figure 1.a) hereinafter referred to as as welded.
2) Design 2: 4-point clamp treatment (figure 1.b) hereinafter referred to as 4Clamp.
3) Design 3: liquid nitrogen cooling heat sink treatment (figure 1.c) hereinafter referred to as HS-N$_2$.
4) Design 4: flow water cooling heat sink treatment (figure 1.d) hereinafter referred to as HS-H$_2$O.
Figure 1. Schematic of the welding treatment process at: a) as welded, b) 4-point clamp, c) heat sink by liquid nitrogen cooling, d) heat sink by flowing water cooling.

2.3. Visual test

Visual test is an important inspection method because it is the first filter to ascertain whether an NDT test is necessary. Important things that need to be done during a visual inspection of the weld joint include:

a) The appearance of weld on the bead, unattractive bead casts doubt on the quality of the weld.
b) The penetration of the weld, the certainty of the weld penetration is very important.
c) Surface defects, can be detected visually but more clearly and accurately can be checked with magnetic powders and penetrating substances (dye penetrant).
d) The welding treatment, slag removal and splash or other treatment must be ascertained by visual observation of the weld.
e) Acceptance criteria as a reference for determining passing visual inspection and NDT must meet all inspection criteria items required by AWS-D1.1. [9].
2.4. Dye penetrant test

The penetrating fluid used in this study is a red penetrant type. Red penetrant fluids can be carried out under white light, while green (fluorescent) penetrant fluids should be carried out using ultraviolet light in dark areas.

The dye penetrant testing steps are as follows [10]:
1. Pre-cleaning with a cleaner liquid.
2. Spraying penetrant liquid, must be "allowed" for a while on the surface of the workpiece in order to fill any defects.
3. Remove penetrant fluid on the surface with a cleaner fluid
4. Using developer fluid (white). Before applying developer fluid, the components must be completely dry. Drying is usually done in a hot air circulating oven.
5. Inspection of the workpiece surface. Inspection results need to be documented on the inspection report form or other records. This can be supported by an indication image or photo, et.al.

3. Results and discussion

3.1. Visual Inspection

Visual inspection of the weld is carried out on both the upper and lower surfaces to see the quality of the weld joint with the direct eye prior to further tests. Inspections are made with the aid of a camera for documentation purposes. Observations are also carried out by referring to the visual test observation instruments that have been established by the AWS D1.1 standard [9]. The results of the visual observation of the weld with a camera, especially the root pass for the as-welded, 4Clamp, HS-N\textsubscript{2}, and HS-H\textsubscript{2}O conditions are shown in figure 3.

Based on the results of the visual inspection of the weld in figure 2, it can be seen that the welding conditions as welded, 4Clamp, and HS-H\textsubscript{2}O show a perfect penetration in all welding lines with a root pass size of 1-3 mm. On the other hand, the HS-N\textsubscript{2} treatment shows the results of welding at 2 points of the weld path identified as lack of penetration [11]. These data indicate that excessive cooling during the welding process reduces the quality of the weld due to a decrease in the weld heat input. Lack of penetration on HS-N\textsubscript{2} treatment that exceeds the threshold on the visual test results in "rejected" or not accept in AWS standard weld quality requirements.

Based on AWS weld standards for visual testing, the cover pass and root pass sections must be observed in detail to ensure weld defects. The criteria for welding imperfections are contained in more detailed items and each has a different pass standard for each item. The AWS standard for visual test passes is applied in this test to detect which clamp and heat sink treatments are suitable for use and to carry out further testing. Table 2 shows the results of the visual welding test that applies the AWS standards to determine the feasibility of welding results with clamp and heat sink treatments.
Figure 2. Welding surface of the root area of the welding treatments: a) as welded, b) 4-point clamp, c) heat sink by liquid nitrogen cooling [11], d) heat sink by flowing water cooling.

Table 2. Visual Test Results of the welded joint

| Parts to be inspected | Types of defects/ imperfection | Test pass standards | As welded | 4 Clamp | HS-N<sub>2</sub> | HS-H<sub>2</sub>O |
|-----------------------|--------------------------------|---------------------|----------|---------|----------------|----------------|
| Cover welding         | Crack                          | No crack            | No crack | No crack | No crack       | No crack       |
|                       | Groove / under fill            | No under fill       | No under fill | No under fill | No under fill | No under fill |
| Porosity              | No more than 1 defect          | No defect           | No defect | No defect | No defect      | No defect      |
| Misalignment          | Max. 1 mm                      | < 1mm               | < 1mm    | < 1mm    | < 1mm          | < 1mm          |
| Under cut (plate thickness < 25 mm) | Max. 1 mm depth | < 1mm               | < 1mm    | < 1mm    | < 1mm          | < 1mm          |
| Irregular bead        | 2mm max variation              | < 2 mm              | < 2 mm   | < 2 mm   | < 2 mm         | < 2 mm         |
| Arc stray             | There is no arc stray> 2 mm    | < 1 mm              | < 1 mm   | < 2 mm   | < 2 mm         | < 2 mm         |
| Spatter               | No spatter                     | No spatter          | No spatter | No spatter | No spatter     | No spatter     |
| Arc crater            | No arc crater                  | No arc crater       | No arc crater | No arc crater | No arc crater | No arc crater |
| Start stop            | The height difference must not be > 0.5 mm | < 0.3 | < 0.3 | < 0.3 | < 0.3 | < 0.3 |
| Excessive reinforcement | Should not be > 3 mm    | 2 mm                | 2 mm     | 1,5 mm   | 1,5 mm         | 1,5 mm         |
| Over lap              | No over lap                    | No over lap         | No over lap | No over lap | No over lap   | No over lap   |
| Root welding          | Lack of penetration and lack of fusion | Not more than 10% | 0 % | 0 % | **30 %** | 3 % |
|                       | Excessive penetration (2 mm or more) | Free (less than 2 mm) | < 2 mm | < 2 mm | < 2 mm | < 2 mm |
| Anguler distortion    | Less than 5 degrees            | 3 degrees           | 1 degrees | <1 degrees | <1 degrees | <1 degrees |

Conclusion of Welding Visual Testing

| Accepted | Accepted | Rejected | Accepted |
|----------|----------|----------|----------|
|          |          |          |          |
Based on the results of the visual welding test in Table 2, it can be seen that the test object for welding in as welded, 4-points clamp, and heat sink by flowing water-cooling are declared "accepted" or passed the test because they qualified the AWS standard criteria. In the heat sink treatment with liquid nitrogen cooling, it is declared "rejected" or does not pass the test because "lack of penetration" exceeds the limit required by AWS. The occurrence of lack of penetration in welding with liquid nitrogen is due to a decrease in welding heat input due to excessive cooling treatment of liquid nitrogen. Thus, the HS-N₂ treatment was declared ineligible to be applied to the welding treatment.

3.2. Dye penetrant inspection

Dye penetrant test is carried out on the upper surface of the weld test specimen to find out defects or surface cracks on the weld test specimen in the as welded condition, 4-points clamp treatment, heat sink by liquid nitrogen cooling, heat sink by flowing water-cooling. The dye penetrant test results are shown in Figure 3.

Based on the results of the dye penetrant test on the cover pass of the weld specimen, it is known that the welding specimen with HS-N₂ treatment was detected that there was a crack at the end of the weld surface (Figure 4.c). Whereas in the welded specimens as welded conditions, the 4Clamp and HS-H₂O treatments were not detected cracks or weld defects. Thus, the decrease in heat input due to HS-N₂ treatment tends to cause weld cracks. This is because the fusion line area does not completely melt due to a lack of heat input, so there is potential for cracks to occur. Based on the location of the cracks in the fusion area, these cracks are classified as cold cracks because they occur at temperatures below the austenite temperature [12].

Figure 3. Dye penetrant test results for welding specimens at: a) as welded, b) 4-points clamp, c) heat sink by liquid nitrogen cooling, d) heat sink by flowing water cooled.

4. Conclusions

Based on the description in the discussion above, it can be concluded as follows:

1. The results of the visual welding test show that the welding treatments include as welded, 4-points clamp, and heat sink by flowing water-cooling have passed the test, while the heat
sink treatment by liquid nitrogen cooling has not passed the test because excessive "lack of penetration".

2. The results of the dye penetrant test on the cover pass of the weld specimen show that the welding specimen with HS-N₂ treatment was detected that there was a crack at the end of the weld surface due to a decrease in heat input due to the HS-N₂ treatment. The welded specimens on as welded conditions, the 4-point clamp and HS-H₂O treatment were not detected cracks and defects.

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