Mechanical Properties and Microstructure at Stainless Steel HAZ from Dissimilar Metal Welding After Heat Treatment Processes

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Abstract. Metallurgy of HAZ at both metals after dissimilar metal welding is important to be evaluated, because differences in metallurgical characteristics due to heating effect on both HAZ might take place after the process. For the case of austenitic stainless steel, metallurgical aspects that should be considered after welding are the formation of chromium carbide (sensitization) and delta ferrite phase. In the present research, focus is given on the HAZ microstructure and hardness both after welding and post-heat treatment process. Microstructure observation was carried out by optical microscope and Scanning Electron Microscope (SEM), whereas hardness testing was carried out by micro-Vickers method. From this study, it can be concluded that the increase in heat treatment temperature can reduce the volume fraction of delta ferrite and chrome carbide precipitation, whereas hardness at the HAZ region decreases after the heat treatment.

Keywords: dissimilar metal welding, post heat treatment, sensitization

1. Introduction
Dissimilar metal welding is a welding process involving two different metals to be joined. It has been applied in various applications including important components in the turbine application. During welding process, the weld area experiences fusion whereas the area of the base metals close to the weld area are still in the solid state condition. However this area affected by heat during the process and is called as heat affected zone (HAZ) [1-3]. Generally heat involved in the HAZ causing microstructure evolution and phase transformation as well in many cases. This metallurgical effect of welding on the HAZ might cause different condition on different metals, i.e. one metal has good influences while the other has worse condition. Therefore finding the optimum condition on both metals to be joined should be find out before performing dissimilar metal welding.
Generally various important welding metallurgies that should be evaluated after welding process are at HAZ. These including, phase transformation [4], microstructure evolution [5], the formation of secondary phase [6] and segregation [7]. For the case of dissimilar metal welding these phenomena might present in the different conditions on different metal, and these could be the opposite condition. In carbon steel, one of condition that should be avoided is the transformation to martensite phase at the HAZ [8,9], whereas for austenitic stainless steel, sensitization that causing grain boundary corrosion [10,11] is an example of phenomenon that should be avoided.

In the previous work, we have evaluated the effect of heat input during welding processes by gas metal arc welding (GMAW) method [12]. In the present work, focus was given on the metallurgical phenomena at the HAZ of stainless steel, which including the formation of sensitization. Heat treatment after welding is commonly performed to eliminate the formation of sensitization [13], and therefore in the present work it was performed evaluation of heat treatment after dissimilar metal welding. Evaluation on the specific effect of post heat treatment on dissimilar metal welding by GMAW method is rarely found in the literature. And therefore this studied is expected to contribute in enriching the knowledge on this specific field of engineering.

2. Experimental method
Dissimilar metal welding in the present works was performed by gas metal arc welding (GMAW) method [12]. Type of carbon steel and austenitic stainless steel used as the base metal is A53 and SS304 respectively, whereas SS308 was used as the filler material. Welding control was performed by varying current, voltage and speed of welding. After welding, heat treatment was performed in the normal atmosphere at temperature of 1010°C and 1120°C and held at this temperature for 13 minutes. Several characterizations were performed after the process, including microstructure observation, hardness measurement and elemental composition characterization. General to detail microstructure observation was performed by optical microscope method, and focus is given on the metallurgical features at HAZ of stainless steel. This observation was supported by hardness test using micro-Vickers method at the same area. In order to confirm the type of metallurgical feature observed by optical microscope and hardness test, scanning electron microscope and energy dispersive spectroscopy (EDS) were also performed, and focus was given on suspicious feature related with sensitization mechanism at the HAZ of austenitic stainless steel.

3. Results and discussion
Figure 1 shows example of microstructure after welding process, showing the weld area and HAZ of austenitic stainless steel. From this figure it can be seen austenite phase at the base metal, and dendritic structure at weld area. At the HAZ area it can be observed the relatively bold line of grain boundary which is delta ferrite in the form of ferrite stringer that is normally formed following rolling orientation and due to heat effect during welding process.

On the other hand Figure 2 shows example of microstructure after post heat treatment processes at temperature 1010°C (Figure 2(a)) and 1120°C (Figure 2(b)). From both figures it can be seen that dendrite structure that was formed after welding process at the weld area had been transformed to the equiaxed grain of austenite after both heat treatment processes. In addition delta ferrite is almost diminished after both heat treatment process, as bold line around the HAZ or fusion line cannot be observed. However minor features in the form of dot feature as shown by the red arrow is considered as the remaining delta ferrite of the sample heat treated at 1010°C. For the case of sample heat treated at 1120°C, this feature is completely diminished. The appearance of delta ferrite is associated with the presence of sensitization as the chromium carbide exist at the boundary between delta ferrite and austenite phase. At high temperature such as the present heating temperature, chromium carbides are dissolved into austenite matrix, and therefore effect of sensitization can be diminished. Another point to be considered is, heat treatment also influences the grain size at the HAZ area, as is shown in the Figure 3. This figure show the data for the sample with different heat input condition, and it can be
observed both heat treatment in the present work increase the grain size and higher as the heating temperature increases.

Figure 1. Example of microstructure after welding processes.

Figure 2 Example of microstructure after post heat treatment process (a) heating temperature 1010°C, (b) heating temperature 1120°C.

Figure 4 shows the effect of heat treatment on hardness at base metal of stainless steel (BM), HAZ and weld metal. It can be seen that for as weld specimen, HAZ show highest hardness of all, however after heat treatment, weld metal become more dominant especially for the sample heat treated at 1010°C. The highest hardness of HAZ is considered due to the formation of chromium carbide at the boundary between austenite phase and delta ferrite. After heat treatment, this carbide is dissolved as previously mentioned and as also shown in the Figure 3, grain growth also takes place during heat treatment. Therefore the hardness after heat treatment is decreased at all area.
Figure 3. Effect of heat treatment on the grain size.

Figure 4. Effect of heat treatment on hardness.

In addition to the above data, Figure 5 shows scanning electron micrograph of as weld sample and after heat treatment. As weld sample show continuous line of delta ferrite which is in accordance with data in the Figure 1, whereas heat treated sample show delta ferrite in the form of discontinuous dot feature which also indicate partial dissolution of carbide after heat treatment. By comparing Figure 5(b) and (c) it can also be observed that sample heat treated at temperature of 1120°C show less delta ferrite as compared with sample heat treated at 1010°C. This condition also suggests longer holding time is required in order to fully diminish delta ferrite as well as carbide in the HAZ of stainless steel. On the other hand, as confirmation on the former data about the occurrence of sensitization, energy dispersive spectroscopy (EDS) characterization was performed on the as weld sample. Characterization was performed by point mode characterization on the small boundary feature at the grain boundary between delta ferrite and austenite (Figure 6(a), and also on the surrounding area (Figure 6(b) covering the feature in the Figure 6(a). It was observed higher carbon concentration for the small feature in the Figure 6(a) (the mass % about 12%) as compared with surrounding area (mass% about 6%). This fact indicates the formation of carbide at the grain
boundary of austenite and delta ferrite as a result of sensitization at the HAZ of austenitic stainless steel during welding process.

Figure 5. SEM observation of: a) as-weld, b) heat treated at 1010°C, c) heat treated at 1120°C.
Figure 6. Energy dispersive spectroscopy (EDS) results of: a) one point feature at the grain boundary austenite shown by the number, b) area shown by the photo.

4. Conclusion
Sensitization occurs after welding at the HAZ of stainless steel with the presence of chromium carbide at the grain boundary between delta ferrite and austenite phase. On the other hand heat treatments applied in the present research are able to partially diminish sensitization. In order to completely diminish the sensitization, heat treatment should be performed at longer holding time. Before heat treatment HAZ has the highest hardness, and highest decreasing of hardness observed after heat treatment at the HAZ.

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