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# A Report of narrow gap welding

## Thông báo về hàn khe hở hẹp

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## Abstract

This paper presents experimental results of narrow gap butt welding of steel plates with greater thickness by using the Metal Active Gas (MAG) welding method. The mechanical properties of the welding joints were examined by metallographic method using the microhardness investigated in some specific submicro structure subzones, such as the weld center zone, heat-affected zone (HAZ), base metal region, and the boundary between the weld metal and the HAZ. The experiment results higlighted the graphical relation between the microhardness and the measuring distance in different subzones. The finding helps to forcast the quality and the loadability of the welding construction.

*Keywords:* Narrow Gap MAG welding; Microhardness of weld metal; Heat Affeted Zone; Base metal region.

## Tóm tắt

Bài báo giới thiệu kết quả nghiên cứu thực nghiệm về hàn khe hở hẹp mối hàn giáp mối các tấm thép độ dày lớn bằng phương pháp hàn kim loại có lớp khí bảo vệ (MAG). Cơ tính các mối hàn được khảo sát dùng phương pháp kim tương học để đo độ cứng tại các vùng tổ chức tế vi đặc trưng, bao gồm vùng trung tâm, vùng chịu ảnh hưởng nhiệt (HAZ), vùng kim loại cơ bản và vùng tiếp giáp giữa kim loại hàn với vùng ảnh hưởng nhiệt ( HAZ).Các kết quả thí nghiệm cho thấy mối liên hệ ảnh giữa độ cứng tế vi và khoảng cách đo tại các tiểu vùng khác nhau. Phát hiện này giúp dự báo chất lượng và khả năng chịu tải của kết cấu hàn.

*Từ khóa:* Hàn MAG khe hở hẹp; Độ cứng tế vi kim loại hàn; Vùng ảnh hưởng nhiệt; Vùng kim loại cơ bản.

## 1. Introduction

Narrow gap welding is an effective solution for joining heavy thick plates because this method offers a small joint cross-section, reducing thermal deformation and welding costs. Therefore, narrow gap welding has been widely applied in ships, construction, nuclear and fossil fuel industries, etc. [1-2]. Applications of advanced butt weld technology for steel plates or pipes with narrow gaps and chamfered (or non-chamfered) specimens in a shielding gas environment have been systematically developed by scientists and industrial practice [3-7]. Recently, remarkable

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results on technological and equipment improvement solutions for (Tungsten Inert Gas) TIG welding [8-9], MAG/Gas Metal Arc Welding (GMAW) have been reported [10-12]. Li et al. [11] successfully built a quality prediction model for narrow gap MAG welding for Q235 steel plates with a groove height of 20 mm. Kim et al. [12] applied narrow gap welding to join steel plates with a thickness of 31.75 mm of combat vehicles. Ngo et al. [13] presented some preliminary research results on both theory and practice of butt welding of steel plates with narrow gaps. They used the steel specimens having a small thickness (up to 20 mm) and large chamfer angle ($\alpha = 30^\circ$ chamfered side). There is limited research assessing the weld quality of extremely thick plate butt welding (up to 50 mm) with narrow gaps and small chamfer angles ($\alpha = 15^\circ$ on each side).

## 2. Materials and method

The sample material used in the experimental welding is SS400 steel. The length, width, and thickness of the workpiece are 300, 100, and 50 mm, respectively. The chamfer angle, which is formed by the vertical plane and sidewall of the specimen, is chosen as $15^\circ$ on each side. Figure 1 shows the workpieces prepared for the welding test and the sample after welding.

(a) (b) (c)

**Fig. 1.** Butt welding of thick steel plate with narrow clearance: (a) Workpieces with small chamfer ($\alpha = 15^\circ$); (b) Fixing workpieces with gap spacing equal to the torch tip diameter; (c) Finished welding sample.

A PLEXTEC® 500x (The Lincoln Electric Company, USA) welding machine was used for the experiments, as shown in Figure 2. The MG70S-6 electrode wire diameter is 1.2 mm. And all the welding tests are conducted under 100% $CO_2$ shielding gas condition.


**Fig. 2.** PLEXTEC® 500x welding machine and welding process parameters.

Figure 3(a) shows the schematic diagram of the MAG welding. The welding tip rotates and simultaneously moves along the gap during welding. Figure 3(b) shows the specimen and welding tip in the gap during welding. Figures 3(c) and (d) illustrate the specimen after welding several layers.

The experiment plan is based on the design of the experiment for 3 process parameters and 3 levels. As a result, total 27 experiments are carried out [10]. Three process parameters include: the welding voltage $U_w = 24 \div 28$ V; the translational velocity of the tip $V_t = 4 \div 8$ m/h; and the rotational velocity of the tip $V_r = 20 \div 30$ rpm/min.

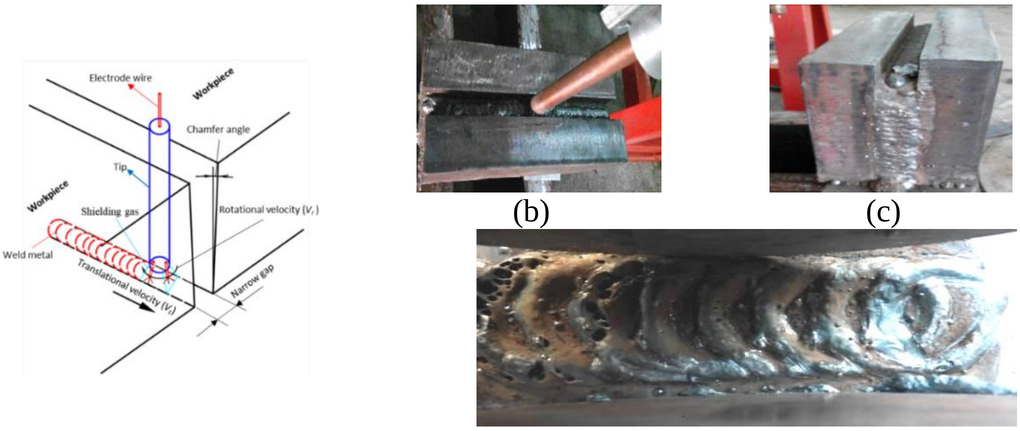


**Fig. 3.** Experiment of MAG welding for butt joints of thick plate with narrow gap: (a) Welding diagram; (b) The welding tip in the gap during welding; (c) Specimen at a time when several completed layers; (d) Surface of a welded layer.

Figure 4 shows the optical microscope (Axiovert 25), which is used to monitor the microstructure of the butt-welded joints.

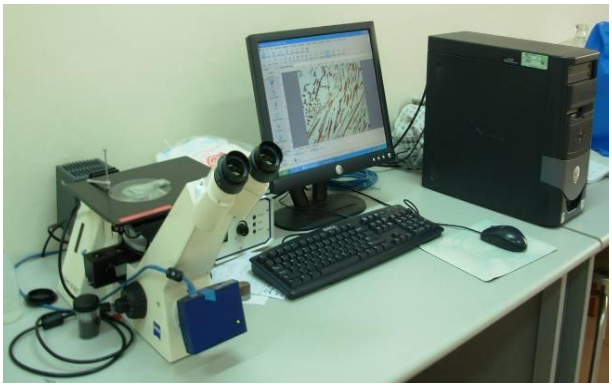

**Fig. 4.** The optical microscope used for monitoring the weld joint microstructure.

In order to investigate the microstructure of the material in weld zones, the cross-section of the welded sample with the narrow gap (10 mm) and small chamfer angle ($\alpha$ = 15°) is divided into 13 areas as indicated in Figure 5. The welded specimen is cut into three parts using a wire electrical discharge machine. These parts are numbered from bottom to top as $M_i1$, $M_i2$, and $M_i3$ (where i is the ith welding experiment). Positions 1, 2, 3 are located at the weld zone center. Positions 4, 5, 6 are on the boundary region between the weld metal and the HAZ. Positions 10, 11, 12 are selected in the HAZ zone. Finally, position 13 indicates the base metal zone near the HAZ.

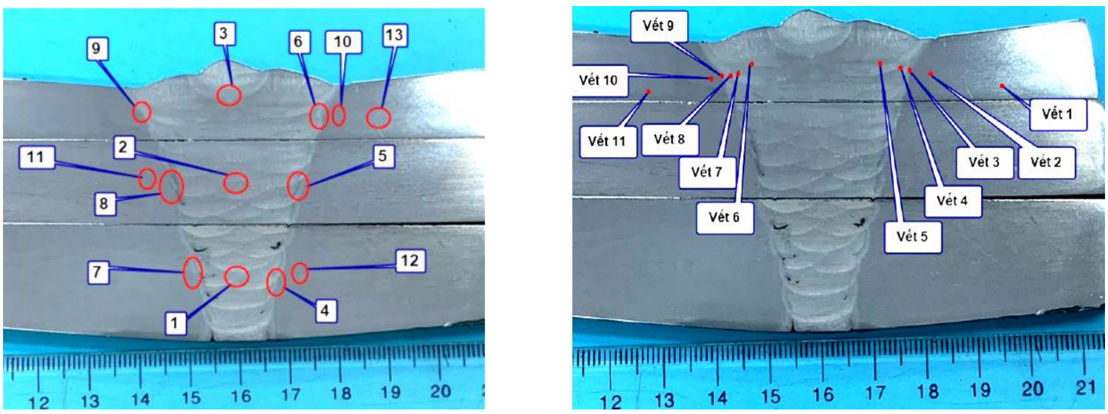


**Fig. 5.** Examined positions of the cross-section of a butt-welded specimen , thickness (10 mm), bevel angle ($\alpha$ = 15°), for microstructure a) and microhardness b)

In this study, the microstructures of 13 positions from 3 different experiments are investigated. In detail, the microstructure properties of following positions and procedure parameters are examined: positions 1, 4, 7, and 12 of experiment 3 ($U_w$ = 28 V, $V_t$ = 4 m/h, $V_r$ = 20 rpm/min; $M_{3}1$); positions 2, 5, 8 and 11 of experiment 2 ($U_w$ = 26, $V_t$ = 4 m/h, $V_r$ = 20 rpm/min; $M_{2}2$); and positions 3,6,9,10, and 13 of experiment 8 ($U_w$ = 26 V, $V_t$ = 8 m/h, $V_r$ = 20 rpm/min; ($M_{8}1$).

## 3. Results and discussion

### *3.1. Microstructure characteristics of narrow gap welds*

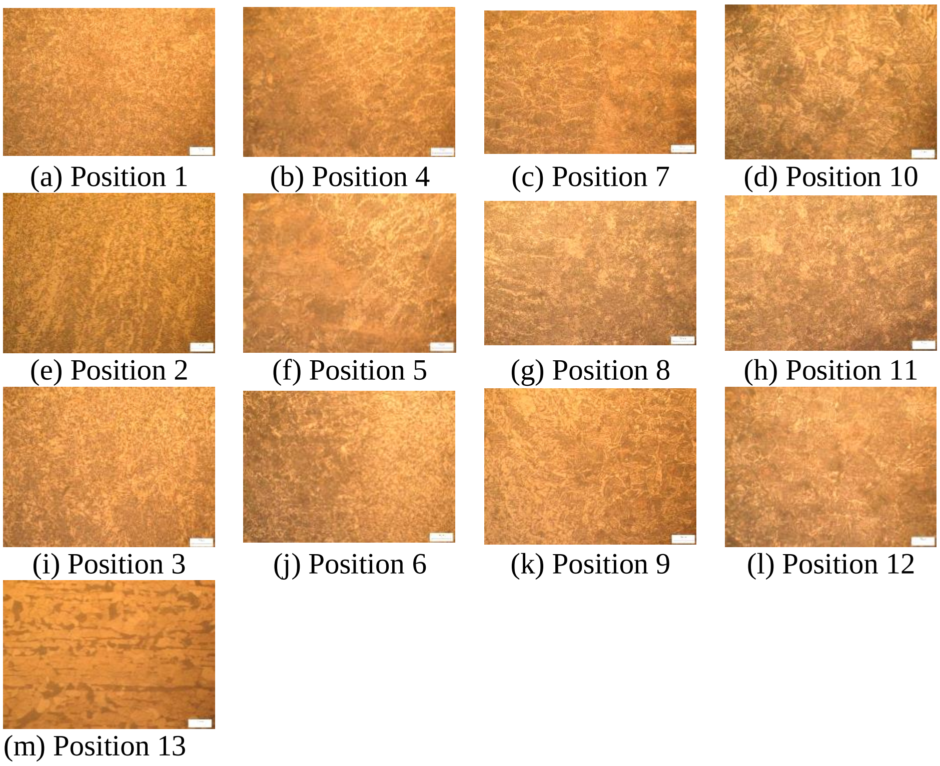


**Fig. 6.** Microstructure of narrow gap welding at 13 positions corresponding to 4 regions of 3 welded samples (magnification = 200): (a-d) Experiment 3 ($M_{3}1$); (e-h) Experiment 2 ($M_{2}2$); (i-m) Experiment 8 ($M_{8}3$).

Figure 6 shows the microstructure properties of the 13 positions on the cross-section of the weld joints. The microstructure properties of the welding center area, including positions 1, 2, and 3, were examined. Figures 6(a) and Figure 6(i) show that the grain structure in the central region is relatively uniform and fine. The grain size of this region is smaller than that of the other regions. However, the microstructures in Figure 6(e) indicate fine and columnar grain structures. This can be explained by improper cooling conditions during welding or intermittent performance during welding. Figures 6(b), (f), and (j) show the microstructures at the boundary between the weld metal zone and the HAZ on the right side of the joint. Figures 6(c), (g), and (k) demonstrate the microstructures at the boundary between the weld metal and the HAZ on the left side of the joint. A good penetration between the weld metal and the base metal on both sidewalls of the joint without defects can be observed. The material structures on the right and left parts are quite similar. The separated zones can be observed clearly, and the grain structure in the region far from the weld center is coarser and larger in size. Figure 6(d), (h), and (l) show material structures in the HAZ. The grain size is coarse and larger than the regions near the weld center. The influence of evaluated temperature on the HAZ is clearly revealed. Figure 6(m) shows a typical microstructure of the base metal. In summary, based on assessing microstructures of welding metal, the quality of welding is good. It can completely meet the basic requirements of welded steel structures using thick plates.

### *3.2. Defects of narrow gap weld*

During the experiment, a small number of samples encountered defects in the weld joints. Figure 7 shows the locations and microstructures of defects of experiment 21 with $U_w$ = 28 V, $V_t$ = 8 m/h, $V_r$ = 20 rpm/min. The defects include lack of interlayer penetration, lack of weld fusion on the sidewalls, porosity (or impurities), as shown in Figure 7(a). Figure 7(b) illustrates the microstructure at the bottom part of the weld where the weld quality is poor due to poor penetration. Figure 7(c) shows a lack of metal penetration between the weld layers. Figure 7(d) demonstrates that the defects are caused by lacking interlayer penetration and weld fusion on sidewalls of specimens. Figure 7(c) shows visible porosity (or impurities) existing in the weld zone.

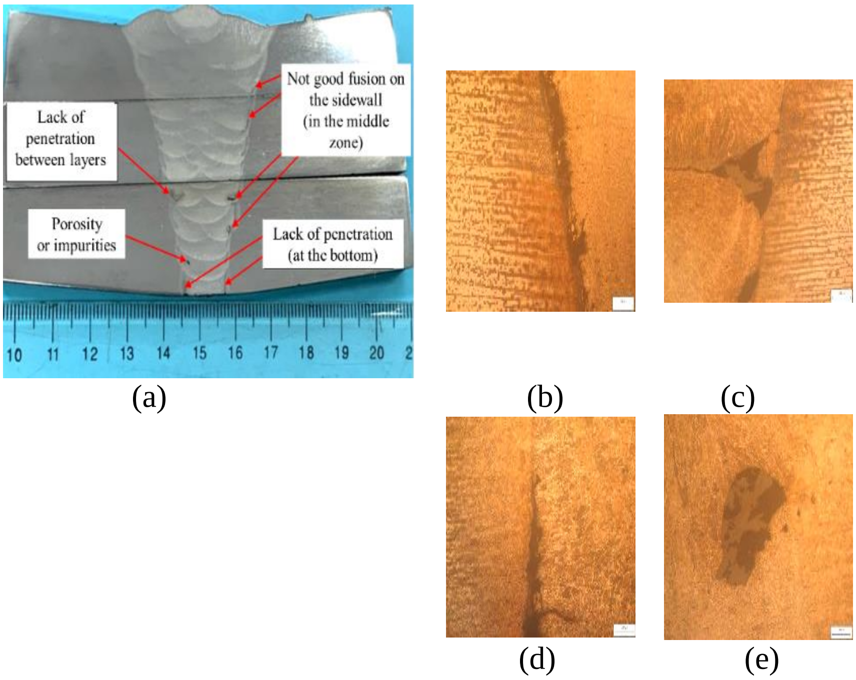


**Fig. 7.** Defects of narrow gap welds: (a) Positions of defects; (b) Defects due to lack of fusion on the sidewall; (c) Defects due to low penetration between layers; (d) Defects due to low penetration between layers and lack of fusion on the sidewall; (e) Defects due to porosity (or impurities) (magnification = 50).

Figure 7(a) shows that the defects mainly appear at the bottom part of the joint. This is because the joint structure with too-narrow gap and small chamfer angle restricts the space required for the necessary movements of the welding tip leads to a poor welding quality. The other defects, such as porosity and non-penetration in the middle part of the joint, could be due to inappropriate welding parameters.

It can be observed that the number of defects in this study is higher than that obtained by welding narrow gap steel plates with a small thickness of 25 mm and a large bevel angle of 30 [8]. Moreover, the joint structure of the weld has a strong influence on the welding quality in the narrow-gap weld.

### *3.3. Microhardness in different specific subzones*

The result of measuring microhardness in different specific subzones : weld zone center; boundary between weld zone center and HAZ ; base metal on the right and left side, accordingly Fig. 5, b , are shown in Tab.3.

**Table. 3**. Microhardness in welding samples of thick steel plates with narrow gap and chamfer angle α = 15$^{O}$

| No | Mark | Position of measuring microhardness - $HV_{0,2}$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Node 1 | Node 2 | Node 3 | Node 4 | Node 5 | Node 6 | Node 7 | Node 8 | Node 9 | Node10 | Node11 |
| 1 | M1 | 172 | 188 | 193 | 194 | 204 | 184 | 206 | 218 | 214 | 226 | 169 |
| 2 | M2 | 196 | 203 | 202 | 227 | 210 | 195 | 187 | 199 | 208 | 213 | 179 |
| 3 | M4 | 172 | 190 | 187 | 187 | 174 | 191 | 195 | 187 | 191 | 194 | 184 |
| 4 | M6 | 199 | 202 | 205 | 209 | 209 | 203 | 211 | 206 | 218 | 198 | 178 |
| 5 | M8 | 212 | 236 | 242 | 248 | 232 | 212 | 238 | 234 | 232 | 225 | 201 |
| 6 | M9 | 174 | 196 | 235 | 234 | 190 | 191 | 200 | 212 | 214 | 239 | 180 |
| 7 | M10 | 186 | 241 | 244 | 225 | 221 | 213 | 218 | 224 | 225 | 234 | 197 |
| 8 | M12 | 196 | 214 | 196 | 215 | 222 | 217 | 227 | 225 | 212 | 210 | 189 |
| 9 | M14 | 189 | 196 | 188 | 192 | 192 | 198 | 212 | 196 | 191 | 186 | 176 |
| 10 | M15 | 186 | 194 | 184 | 198 | 192 | 187 | 189 | 185 | 189 | 191 | 178 |
| 11 | M17 | 184 | 223 | 214 | 215 | 222 | 204 | 194 | 218 | 226 | 215 | 176 |
| 12 | M18 | 173 | 191 | 204 | 191 | 179 | 182 | 191 | 192 | 213 | 203 | 195 |
| 13 | M19 | 182 | 177 | 184 | 186 | 198 | - | 190 | 185 | 192 | 189 | 167 |
| 14 | M20 | 179 | 190 | 196 | 184 | 195 | - | 216 | 184 | 221 | 200 | 197 |

**Note :** "Vết " = " Node", *Vết 1 – Parent metal on the right side; Vết 2 – Heat -Affected Zone(HAZ 1)on the right side; Vết 3 – Boundary between the weld metal on the right side (B.G.H 1) and HAZ 1; Vết 4 – 1 mm away from B.G.H + HAZ 1; Vết 5 – 4 mm away from boundary between weld metal ( B.G.H 1) and HAZ 1; Vết 6 - 4 mm away from boundary between weld metal on the left side( B.G.H 2) and Heat – Affected Zone on the left side( HAZ 2); Vết 7 - 2 mm away from ( B.G.H 2)and HAZ 2; Vết 8 - 0,5 mm away from boundary between ( B.G.H 2) and HAZ 2; Vết 9 – In boundary between weld metal on the left side (B.G.H 2) and HAZ 2; Vết 10 – In HAZ 2 on the left side; Vết 11 – In weld metal on the left side.*

In the Fig.8,9 : the graphical presentation of change the microhardness from the results in Tab.3

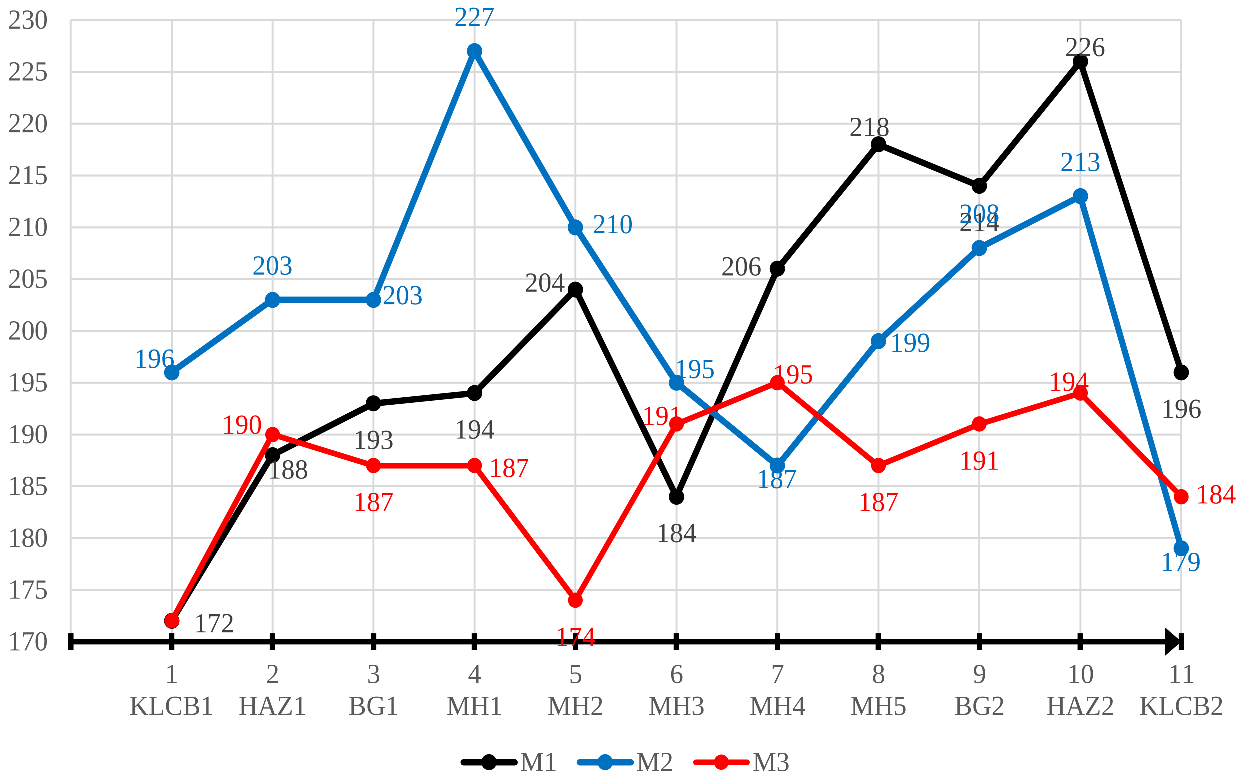


**Fig 8.** Hardness in positions : node 1, node 2 & node 3

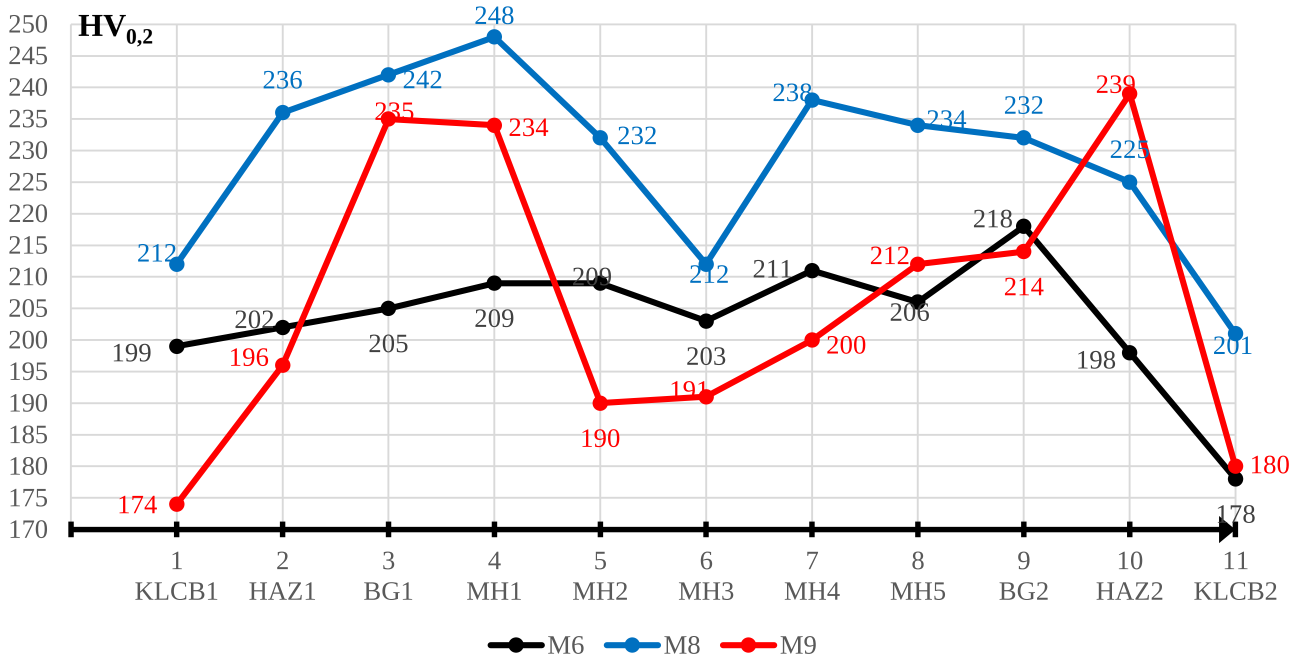


**Fig 9.** Hardness in positions : node 6, node 8 & node 9

## 4. Conclusion

In this study, butt welding of heavy thick steel plates with a narrow gap and small bevel angle was performed using the MAG welding method. Microstructures of 4 regions of the joints showed the change in shape and size of the grains following the theory of butt welding. The weld quality generally satisfies and ensures the high strength of joints. However, a small number of welded samples still present defects such as lack of interlayer penetration, lack of weld fusion on the sidewalls, porosity (or impurities). Therefore, optimization of welding process parameters to achieve high welding quality needs to be further studied. On the other hand, from the results of weld defects, it is necessary to consider the effect of other factors (such as cooling conditions, delay time when the arc approaching the sidewalls) on the weld quality.

The characteristic of microhadness change taken from tested samples in this work is compared with the microscopic structure in the publication of the research team [13]. It proves that the weld quality is equivalent in case of narrow gap but the chamfer angle is twice higher. It is acknowlegdes the advantage of the weld joint with the smaller chamfer angle ($\alpha = 15^o$) against $\alpha = 30^o$ due to saving of the energy consumption,welding consumables.

## Conflicts of Interest

The authors declare no conflict of interest

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