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To cite this article: H. Ates, M.E. Cakir, A. Kurt, M. Turker & I. Uygur (2014) The microstructure and mechanical properties of joints of technical-grade aluminium gas welded with oxygen–hydrogen flame, *Welding International*, 28:10, 762-765, DOI: [10.1080/09507116.2012.753226](https://doi.org/10.1080/09507116.2012.753226)

To link to this article: <https://doi.org/10.1080/09507116.2012.753226>



Published online: 07 Mar 2013.



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The microstructure and mechanical properties of joints of technical-grade aluminium gas welded with oxygen–hydrogen flame

H. Ates^{a,b,c}, M.E. Cakir, A. Kurt^{a,b,c}, M. Turker and I. Uygur^{a,b,c}

^a*Faculty of Technology, Gazi University, Ankara, Turkey;* ^b*Industrial High School of Golbaşı, Ankara, Turkey;*

^c*Faculty of Technical Education, Duzce University, Duzce, Turkey*

The goal of this study was to investigate the weldability of aluminum by using the oxy-hydrogen welding technique. Specimen dimensions were 1.5 mm in thickness and 80 mm in length. Microstructural investigations on the cross-sectional area of the weld zone were also carried out in order to compare weld metal and HAZ depending on the welding gases. Tensile strength and microhardness tests were carried out and the results were compared. Test results have shown that the yield strength of the samples welded with oxy-acetylene is higher than that of the samples welded with oxy-hydrogen.

Introduction

During his research in 1766, Henry Cavendish discovered an unknown gas, which he called ‘fire air’. It was only in 1783, as a result of research work, that Lavoisier named the newly discovered element ‘Hydrogenium’ (hydrogen) [1]. The symbol for hydrogen is the letter H, its atomic weight is 1.00797, density (0°C, 760 mm Hg) – 0.08987 g/l and its atomic number is 1. Despite the fact that hydrogen is one of the most common elements in the universe, in its free state it is very rare outside of the upper layers of the atmosphere. It is a colourless and odourless gas which often occurs together with other elements, forming compounds. Hydrogen is flammable, and the product of combustion is water vapour. Hydrogen has 2.75 times more energy than the same amount gasoline [2]. Energy supply is one of the key factors to address the economic problems of many countries. In many countries, fossil fuels are still used, such as coal or oil, which results in environmental pollution. Recently, numerous activities have been focused on the use of hydrogen as an alternative energy source, mainly due to high energy prices, limited fossil fuel resources and their areas of occurrence, as well as due to the state of the environment. Renewable energy sources are more attractive and seem to be a fundamental solution to the above problems. Hydrogen is the most serious candidate in this respect, because it can be used in many applications, it is easy to transport, has high energy efficiency and is inexpensive and environmentally friendly. Strictly speaking it is not, however, a natural fuel, since it practically does not exist in its free form. It can be obtained by chemical synthesis from carbon, water and natural gas. It can also be easily obtained from distilled water, the stocks of which are practically endless, and the side product of this reaction is only water vapour [3]. Hydrogen is used in a variety of welding procedures, such as atomic hydrogen welding, hydrogen flame gas welding, thermal cutting and soldering. It is used in various industries, such as automotive, chemical, aerospace, telecommunications, joining processes and maintenance work. In welding processes, hydrogen is preferred to acetylene, primarily due to being easier to obtain and cheaper. Hydrogen has been used for a long time as fuel gas for welding [4]. The development of hydrogen production by hydrolysis increased the popularity

of its use as fuel gas in welding processes [5]. However, replacing acetylene completely with hydrogen is not currently possible. Hydrogen is preferred for cutting and soldering, whereas acetylene is most widely used as fuel gas for welding processes [4]. The process and results of comparative tests of welded joints of technically pure aluminium, made by gas welding using acetylene and hydrogen flame, have been shown below. The comparison takes into account the obtained results with respect to structural construction of joints and their mechanical properties.

Materials and testing

The chemical composition of the basic material used for testing is given in Table 1. Dimensions of test samples for welding were 125 × 80 × 30 mm, as shown in Figure 1. Before welding, the samples were polished with 240 grit SiC sand paper. Powdered flux for aluminium was also used. After welding, the joints were turned into samples (Figure 2) for tensile strength testing. For each set of welding conditions, the tensile strength test was carried out three times, and the results are presented as their arithmetic mean. Samples for metallographic examination were cut from the welded joints using electro discharge machining. The samples were polished and etched with the Keller reagent. This was followed by metallographic microscope examination and Vickers microhardness measurements of the base material (1), the transition zone (2) and the joint itself (3). Hardness testing was carried out using the Vickers hardness measurement method with a load of 50 g.

Test results and discussion

Tensile strength test results

Views of samples after stretching and breaking are shown in Figure 3(a),(b). It can be seen that in all cases the fracture occurred in the joint, and immediately prior to the break each sample developed a specific groove, suggesting a plastic fracture. Tensile curves for welded joints using hydrogen and acetylene flame are shown in Figures 4 and 5.

Table 1. Chemical composition of base material.

Element	Si	Fe	Cu	Mn	Mg	Cr	Ti	Al
% m/m	0.119	0.277	0.05	0.09	0.08	0.003	0.011	Rest

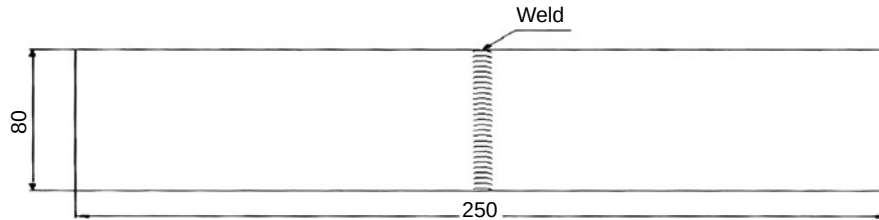


Figure 1. Dimensions of weld joints.

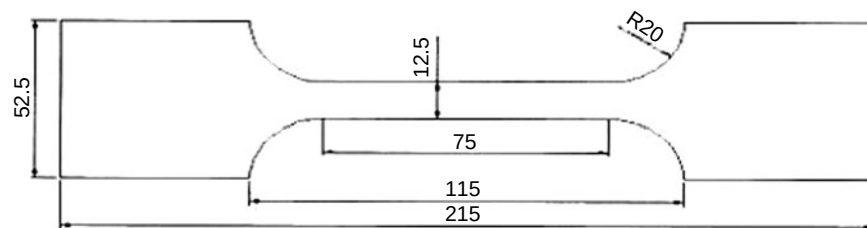


Figure 2. Shape and dimensions of samples for tensile tests.

The results of tensile tests for welded joints made using hydrogen flame, were as follows: average tensile strength of 86 MPa, breaking stress of 32 MPa and elongation of 23%. For welded joints made using acetylene flame the average tensile strength was 82 MPa, breaking stress 33 MPa and elongation 29%. It can be seen that the tensile strength of welded joints made using hydrogen flame is higher than for acetylene flame, however, the reduction in

breaking stress is similar. These differences in strength properties can be explained by hydrogen brittleness and the width of the heat-affected zone, which is much narrower in the case of joints made using hydrogen flame.

Hardness testing

Hardness measurements were performed for the weld itself, the transition zone, as well as for the base material of the welded joints. The measurement results are shown in Table 2. It can be noticed that comparable hardness values have been obtained for both fuel gases in the transition zone, whereas the hardness within the weld joint is higher for welded joints made using hydrogen flame. The weld is likely to show the effect of gases from the flame. The presence of hydrogen and oxygen in the weld area may result in the formation of compounds such as Al_2O_3 and AlH_3 , whereas for oxy-acetylene welding only one type of carbide may occur (Al_2C_3). In addition, the flame gases can influence the rate of cooling during welding. The increase in hardness results in an increase in tensile strength, however, it may also lead to a decrease in the plastic properties of metallic materials. This is a typical phenomenon which can be observed for different welding processes of different metals [6,7].

Microstructure

The microstructure of the joints made from technically pure aluminium using acetylene and hydrogen flame are shown in Figure 6(a),(b). In the pictures dendrites can be observed, which have been subject to very rapid cooling.

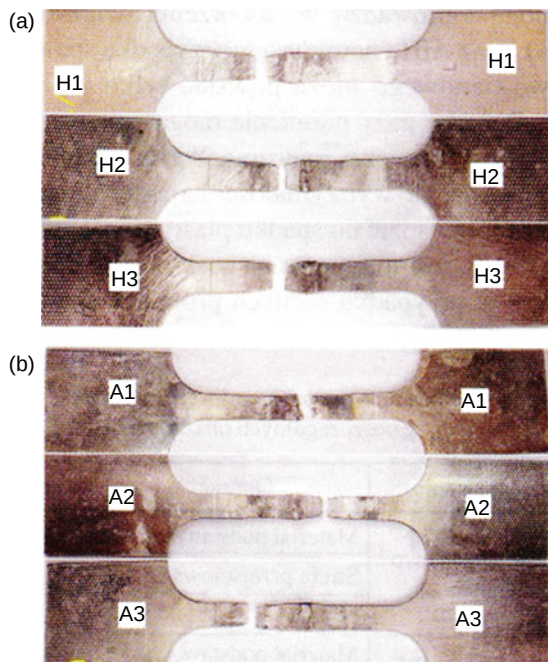


Figure 3. View of samples after fracture of joints welded using hydrogen flame (a) and acetylene flame (b).

Most dendrites have formed from existing grain and grew towards the centre of the weld. The solidification process generally takes place in a direction perpendicular to the temperature gradient, where changes occur caused by the

welding and cooling speed. This is a typical phenomenon for metal welding. This type of hardening is called epitaxial solidification [9,10] and is caused by the large amount of heat input during welding. The heat also affects

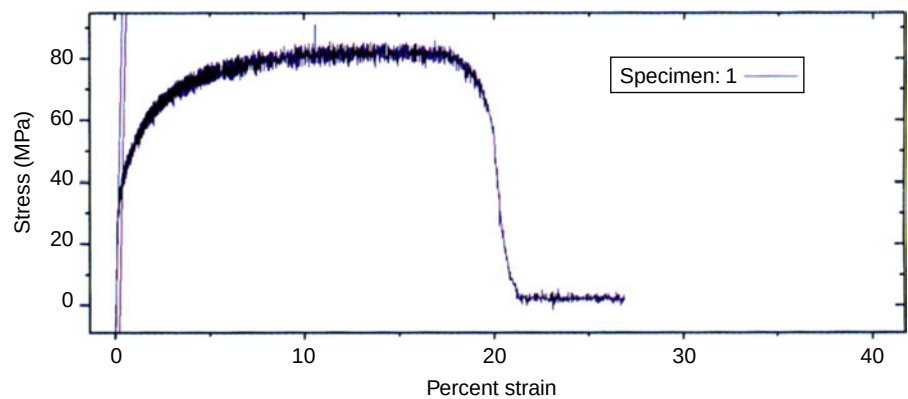


Figure 4. Tensile curves of aluminium joint welded using acetylene flame.

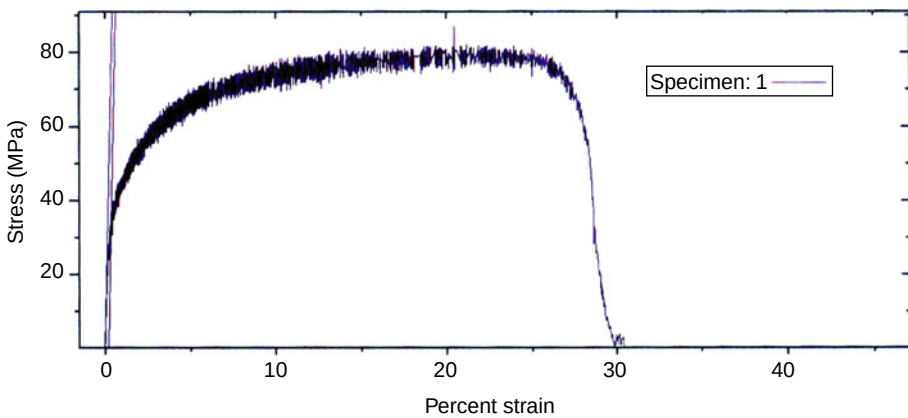


Figure 5. Tensile curve of aluminium joint welded using acetylene flame.

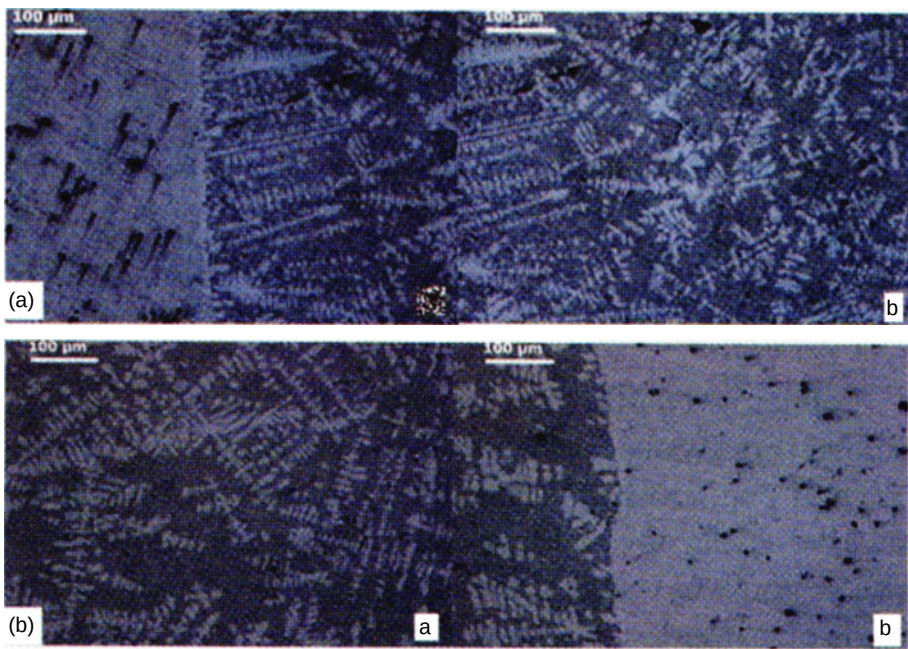


Figure 6. (a) Microstructure of a joint welded using acetylene flame: a, base material; b, weld. (b). Microstructure of a joint welded with hydrogen flame: a, weld, b, base material.

Table 2. Hardness values measured in individual areas.

Welding process	Area	Hardness (HV)
Oxy-hydrogen welding	Base material	30
	Transition zone	29
	Weld	70
Oxy-acetylene welding	Base material	30
	Transition zone	28
	Weld	67

the weld, where a coarse-grained structure with long dendrites can be observed, completely different from the structure of the base material. The structure is similar for flame welding with both gases. It may be noted, however, that in the case of the hydrogen flame, the amount of dendrites is significantly smaller and they are shorter. This shows that welding using hydrogen flame introduces a smaller amount of heat to the material.

Conclusions

Based on the conducted strength tests and metallographic examination of joints of pure aluminium welded using the oxy-acetylene and oxy-hydrogen methods, and on the basis of obtained test results, the following conclusions can be drawn:

- (1) The tensile strength of joints welded using hydrogen flame was higher than for joints welded using acetylene flame. Higher strength results in a slight decrease in plastic properties.
- (2) The hardness of joints welded using hydrogen flame is higher than for joints welded using acetylene flame.

- (3) Both tested welding processes result in the formation of long dendrites and coarse-grain structures in the weld and in the transition zone. The distribution and shape of the dendrites was dependent on the welding speed, the cooling rate and the speed of melting.

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