OXY-ACETYLENE DIFFUSION WELDING OF PLAIN CARBON STEELS

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ABSTRACT

A simple practical method for diffusion welding of steel components, in air, was developed. Specially designed oxy-acetylene ring burner was used for heating the specimens up to 1273 K. Two main advantages could be gained by using the designed burner. Firstly, very short heating up times were obtained. Secondly, the reducing zone of the oxy-acetylene flame was used as a protective atmosphere during the welding process.

A series of plain carbon steel specimens ranging from 0.17% C to 1.1% C were, successfully, diffusion welded in air. A thin carbon rich layer was wrapped around the specimen at the periphery of the welding zone to act as a sealing ring and reduce oxidation. The specimens were heat treated and microhardness, impact, bending and tensile tests were conducted. The yield strength of the welded joints was found to decrease with increasing carbon content up to the eutectoid composition. However, above 0.8%C the yield strength increased with increasing carbon content. Metallographic examinations of the diffusion welded joints revealed the existance of ferritic bands close to the welding interface. The observed microstructure features were correlated with the differences in strength of various steels.

INTRODUCTION

In the simplest case two flat clean surfaces can be joined by diffusion bonding, if they are heated while held together by an applied pressure. This results in micro-deformation of contacting surface asperiteis. As the yield stress of the material decreases during heating up, to the bonding temperature, further micro-deformation of the contacting asperities occurs. Once the bonding temperature has been reached deformation of the surfaces continues by creep mechanisms until the only interface regions, not in contact, are in the form of lenticular pores. Finally most of these are eliminated by vacancy diffusion mechanism.

Pressure, temperature, and time are the three major factors which influence

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bond strength. In addition other factors affect the bond quality such as atmosphere, flatness, surface finish, and surface cleanness.

The main advantage of diffusion welding is that it produces joints which are strong as the base metal itself [1] . Diffusion welding does not change the microstructure of the parent metal. Defect free joints are difficult to make by conventional welding methods [2]. Fusion welding recrystallisation, [3], alters mechanical properties but that does not occur in diffusion welding. It is suggested that dissimilar metals could be joined by diffusion welding as easily as if two parts of the same metal are welded.

The present investigation is an attempt to study the possibility of welding, in air, steel parts having different carbon contents using the diffusion welding technique. The role of protective atmosphere during diffusion welding of steel was well documented [4,5]. However work on diffusion welding of steel, in air, gave mechanical properties inferior to those obtained when welding was conducted under vacuum.

EXPERIMENTAL PROCEDURE

Plain carbon steels of various carbon contents ranging from 0.17% up to 1.1% were used. Chemical analysis of the specimens is given in table 1.

Table-1. Chemical composition

Element / Type	C%	Mn%	S%	P%	Si%	Cr%
St.15*	0.17	0.5	0.045	0.039		
St.20	0.22	0.5	0.045	0.039		
St.30	0.32	0.5	0.045	0.039		
St.45	0.55	0.65	0.045	0.039		
St.Y8	0.8	0.23			0.23	0.2
St.Y9	0.9	0.23			0.23	0.2
St.Y11	1.1	0.23			0.23	0.2

*Steels were designated according to GOST standards.

The steels were obtained in the form of circular rods ≃ 24 mm diameter. Tensile specimens of 10 mm diameter and 50 mm length were prepared by turning, grinding and polishing. The two parts of the specimen, to be welded, were then wrapped by a thin carbon layer around the periphery of the welding zone to act as a sealing ring reducing oxidation.

A specially designed ring burner was used for heating up specimens to the welding temperature. The welding apparatus consists of ring burner and hand press Fig.1. The purpose of using hand press was simply to maintain the two parts of the specimen in an intimate contact during the welding process. Design calculations and assumptions were made to avoid flash-back of the burner and to obtain uniform heating. Full details of these calculations and description of equipments are given elsewhere [6]. The ring burner was water cooled efficiently for six hours of continuous

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working. Temperatures for heating and cooling cycles of specimens were measured by two calibrated chromel-alumel thermocouples. A temperature versus time caliberation curve was established for specimens heated by the burner.

A prelimenary study of the effect of surface finish on the quality of diffusion welded joints indicated that a surface finish of 1 μ_m centre line avarage gives an optimum welding strength. Therefore, it was decided to give a surface finish of that value to all of the mating surfaces perior to the welding process. The main variables, i.e. pressure and temperature were selected to be very close to those recommended in literature |1,4,5 and 7|. Pressure of 4 N/mm^2, temperature of 1273 k and rate of heating of 293 k/sec. were used.

Specimens were heat treated, after welding, at a temperature of 1123 k for two hours followed by furnace cooling. The main aim of post heat treatment was to allow further diffusion to take place and complete the primary welding stage caused by oxy-acetylene heating. Specimens were then sectioned, polished and etched in 2% Nital and inspected by optical microscopy to study the effect of welding conditions on the microstructure. Mechanical tests were conducted to evaluate the strength of the welding interface of diffusion welded joints. Yield strength, bending strength, impact strength and microhardness across the welding interface were measured.

RESULTS AND DISCUSSION

EFFECT OF PARENT METAL COMPOSITION ON INTERFACE PROPERTIES OF DIFFUSION WELDED STEELS

The variation of interface yield strength as a function of carbon content is shown in Fig.2. The interface yield strength rapidly decreased, with increasing carbon content of base metal, to a minimum value of 220 MN/m^2 at approximately 0.8%C which represents the eutectic composition. Specimens of higher carbon content, above 0.8%C, showed a corresponding increase in welding interface yield strength with further increase in carbon content. Similar behaviour was observed for the variation of bending strength as a function of carbon content Fig.3. On the other hand the change in impact strength as a function of carbon addition is shown in Fig.4. As expected, opposite trend of those observed for yield and bending strengths is obtained. The present results are in close agreement with those previously reported |1,4,8 and 9|.

It is well known that, if heating is conducted above AC$_1$ for hypoeutectoid steel, transformation of pearlite to austenite occurs as a result of diffusion process. This diffusion process is associated with the movement of carbon atoms over considerable distances |10|. It is also known that the austenite stability increases as a function of carbon content if an isothermal decomposition of pearlite to austenite is taking place |8|. This, in its turn, indicates that an increase in carbon content should decrease the transformation rate and consequently the diffusion rate.

Upon further increase in carbon content, above eutectoid composition, the austenite stability is again reduced |8| . Therefore the diffusion rate is increased and according to the above argument should lead to an increase in the tensile strength. In addition, for hypereutectiod steels both of pearlite and cementite phases are present. The volume fraction of cementite phase increases with increasing carbon content of steel. Thus the yield strength should increase significantly with increasing the amount of cementite phase which is hard and brittle.

Finally, it should be pointed out that there is a possibility of tiny oxide films formed at the interface regardless of all the surface cleanity precautions. The oxygen, dissolved in the metal, leaves behind small pores. Then the vacancies forming the pores, would diffuse out according to vacancy diffusion mechanisms |1| and the rate of their diffusion would definitely be related to the carbon content of the specimen. Thus low rate rates of diffusion result in large number of interface cavities and consequently lower strength of the welded joints.

METALLOGRAPHY OF DIFFUSION WELDED JOINTS

In the present work, specimens of 0.22%C were used to study the effect of welding conditions and heat treatment on the interface elimination. As shown in Fig.6, complete elimination of the interface and interfacial grain growth is observed at the interior of specimen annealed for two hours at 1123k. However, it should be pointed out that partial elimination of interface was observed, for specimens inspected perior to annealing. Fig.7, indicating that post heat treatment has an essential role for completion of the diffusion welding process.

A prominant feature of the microstructure of most welded joints was the presence of a ferritic band close to the welding interface. The identification of this band was further confirmed by microhardness measurement Fig.5. The presence of such a band , which is probably due to slight decarburization of the surface, would consequently result in lowering the strength of the welded joint compared to the parent metal strength. This prediction, based on metallographic observation, is supported by tensile test results which showed that the observed strengths of diffusion welded joints were less than those of the base metal by approximately ten percent.

CONCLUSIONS

1. Plain carbon steels could be diffusion welded in air at temperature of 1273 and under pressure of 4 MN/m^2 using the reducing zone of the oxy-acetylene flame as a portective atmosphere and a thin layer rich in carbon.

2. Strength of weld joints almost equal to that of the base metals could be obtained if surface finish of 1 μm (CLA) or less is used.

3. Complete welding interface elimination, as determined by the optical microscope, gives qualitative judgement on the success of diffusion welding process. However, mechanical testing should be made if a quantitative assessment is required.

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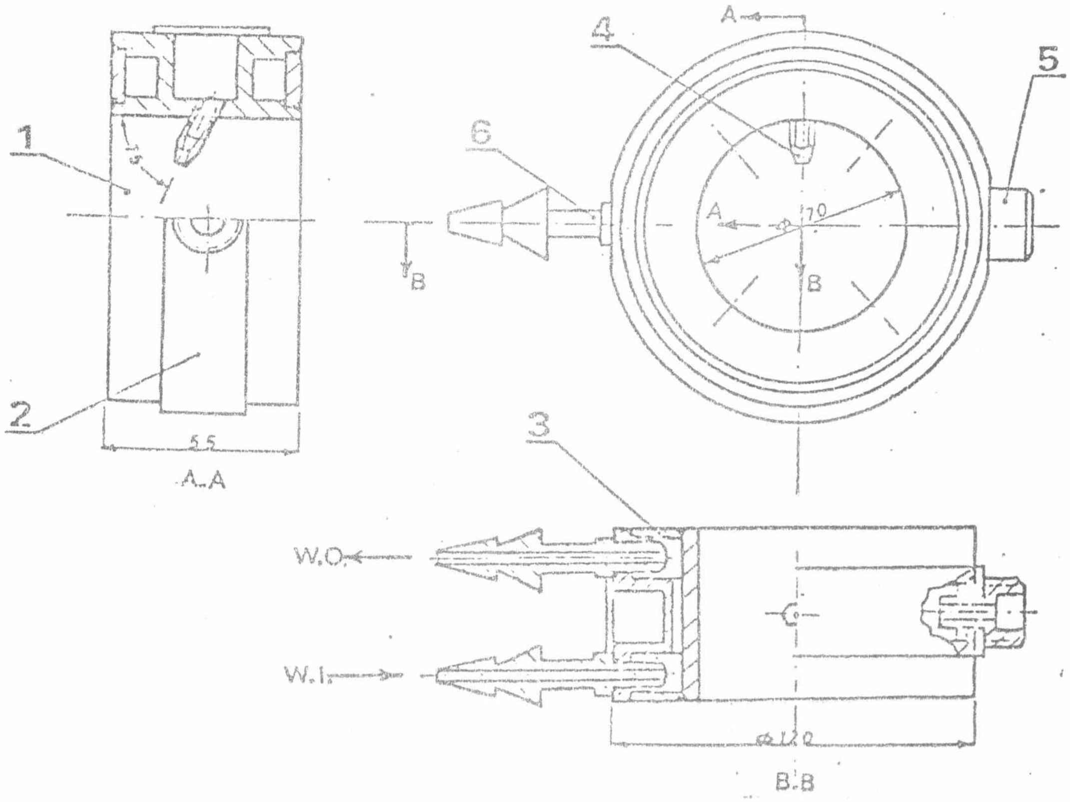

Fig.1 The specially designed ring burner used for diffusion welding

1-Burners body
2-Gas cover
3-Water cover
4-Tip
5-Gas inlet nut
6-Nipples
7-Connecting piece

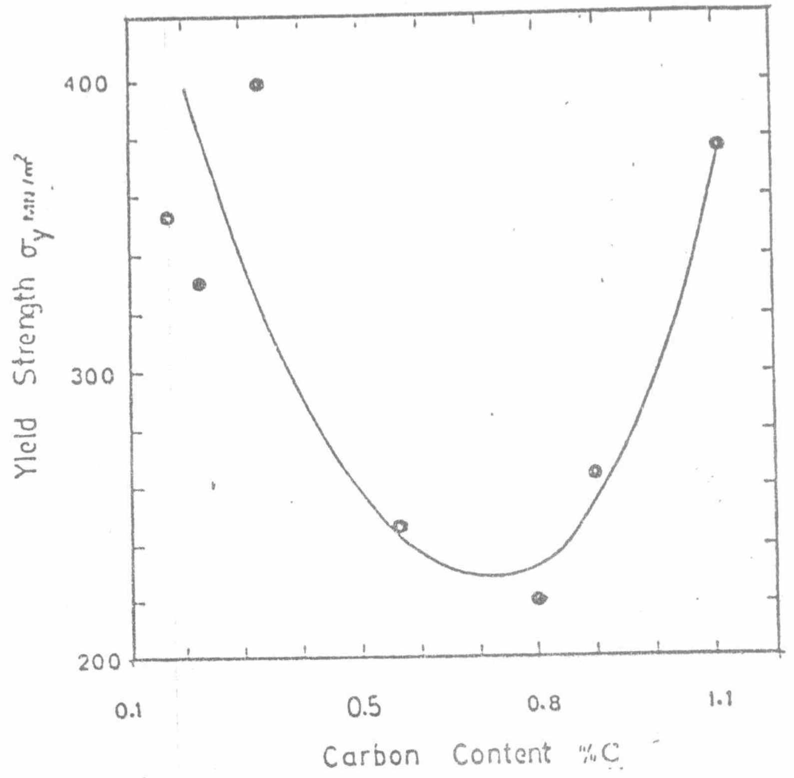

Fig.2 Tensile yield strength of the welding interface as a function of carbon content

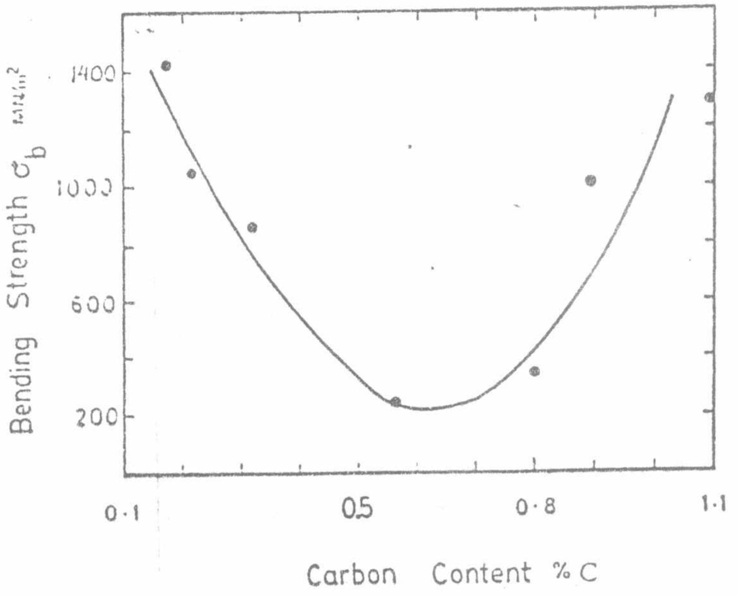

Fig.3 Bending strength of the welding interface as a function of carbon content

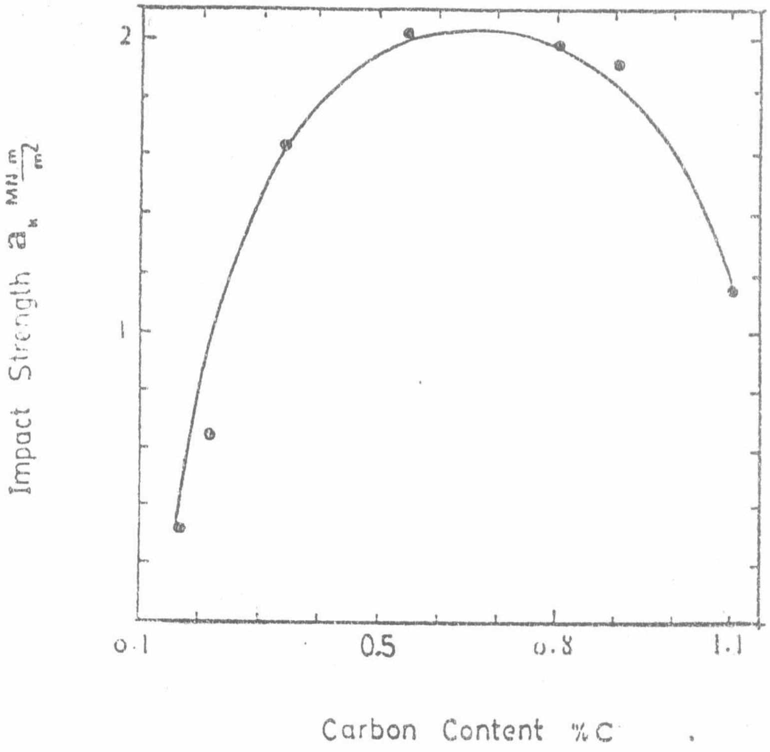

Fig.4 Impact strength of the welding interface as a function of carbon content

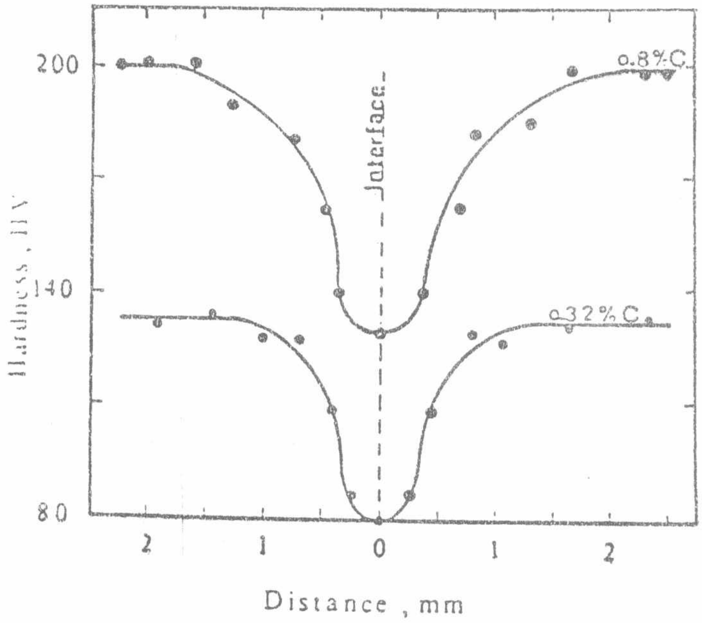

Fig.5 Microhardness distribution across the welding interface.

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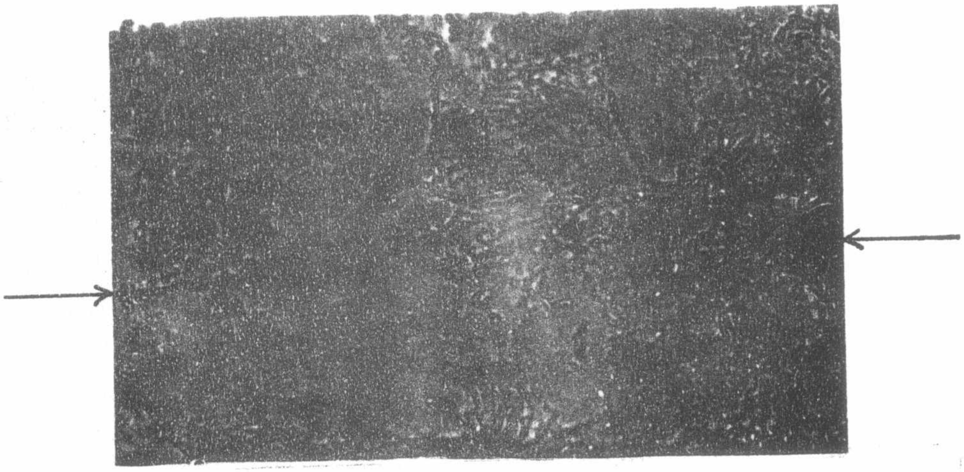

Fig.6 Micrograph of 0.32% C steel showing complete elimination of the post heat treated welding interface.x 1000.

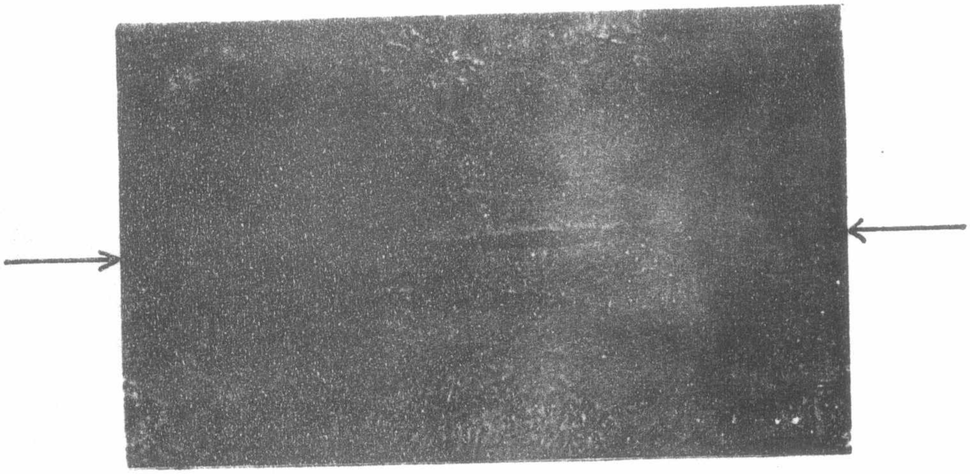

Fig.7 Micrograph of 0.32% C steel showing partial elimination of the welding interface before annealing.x 1000.