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Optimizing tensile strength of low-alloy steel joints in upset welding

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ABSTRACT

Purpose: Purpose In resistance upset welding, the heat is generated by resistance of the interface of abutting surfaces to the flow of electrical current in heating and post-weld heating stages. Upset welding typically results in solid-state welds with no melting at the joint. In this paper, the effect of process parameters including heating and post-weld heating power and their corresponding duration along with interference, on the tensile strength of the welded joint are experimentally investigated.
Design/methodology/approach: The operational ranges of five process parameters are identified. Sufficient numbers of samples are manufactured and subsequently their mechanical strength is quantified using tensile tests. Then variation of the strength versus the process parameter is evaluated. Metallographic studies are performed that provide metallurgical insight to the bond.
Findings: The results suggest that tensile strength of the joint, with variation of each investigated parameter, time, current, and electrical power has an optimal point which shows the optimized set of welding parameters. Also the effect of post-weld heating on the tensile strength is evaluated and shows that this parameter has a remarkable effect exceeding 50% improvement in tensile strength.
Research limitations/implications: Should the percentage of power consumption replaced by current; a better comprehension of the process could be achieved.
Practical implications: The results recommend that the effect of post-weld hating merits more investigation.
Originality/value: The results contribute to a better understanding of the upset welding process. More over this paper shows significance of post-weld heating in maximum tensile strength of the weldment that has not been noted as an important upset welding process in other literature.
Keywords: Welding; Upset welding; Resistance welding; Tensile strength

1. Introduction

Upset welding (UW) is a resistance welding process utilizing both heat and deformation to form a weld. The heat is generated by three factors: resistance of the joining surfaces to the flow of electric current, frictional effect and conversion of deformation energy to heat [1]. The deformation at the welding joint is resulted from applying a force on the joint augmented by the heat generated due to electrical resistance. UW typically results in solid-state welds. The deformation at the welded joint provides tight contact between clean adjoining surfaces, allowing formation of strong metallurgical bonds. The bond quality is determined by degree of grain growth and weld length. If any melting does occur during UW, the molten metal is typically extruded out of the weld joint area but with a chance of entrapment. Solid-state UW has advantages compared to typical fusion welding processes. These advantages are due to simplicity of the welding process and the resulting solid-state weld microstructure.

Of the first reported developments on UW was the work on magnetic resistance upset welding of stainless steel 304 plates with different thicknesses at NASA Lewis Research Center [2]. Resistance welding of nuclear waste containers was another application of this technology [3]. The same application was further reported in [4,5,6] where in [4] Kanne examined the properties of upset welded cylindrical and spherical components. Cannell and Sessions [5] used UW for welding canisters made of 304L stainless steel. Research from Eggret and Dawson [7] discussed assessment of thermoviscoplastic model of UW process by comparing experiments and finite-element analysis method. Bezprozvannyi et al. [8] reported upset welding of high-speed steel to carbon steel with a current regulation system for controlling special cycle welding at Paton Welding Institute. Upset butt welding process parameters such as current and welding length on the microstructure and hardness of the weld in high strength low alloy steel weldment were studied by Ghosh, Gupta and Goswami [9]. Miyazaki, Saito, and Ichikawa [10] examined upset weldability of Nb-bearing high strength steel of 600 MPa. They found that the higher the welding current density, shorter is the required upset length to produce a high quality weld and the required upset length can also be reduced using lower welding force. Kanne [11] also reported applicability of UW process to weld a variety of stainless steels and aluminum alloys along with refractory metals. Shieh and Chang [12] presented a study of UW process in wire drawing for obtaining the optimum parameters of the operation for a better distribution of hardness in the wire. Cannel et al. [13] further reported on optimization and reliability of UW process. In a study by Kang, Min, and Kim [14] the upset weldability and formability of a particular kind of material (SPCC) was investigated. The results showed that the formability of upset welded SPCC steel sheet was little lower than that of the parent material. Application of UW process was recently extended to welding of cast iron parts by Shakhmatov and Shakhmatov [15].

In this paper, the effect of welding area, heating and post-weld heating power and time on the tensile strength of the welding joint are experimentally investigated. In the published literature post-weld heating in UW process is one of the least investigated issues and therefore merits more consideration. The variation of the strength versus the process parameters is evaluated through welding tensile tests and metallurgical studies.

2. Design of Experiments

In resistance UW process the surface bond at the interface of the two joining surfaces is formed due to temperature increase caused by resistance against the current passing through the joint and at the same time plasticizing force at the interface. Therefore the process parameters that affect the quality of the weld and hence the weld strength are: heating step duration, current in the heating step; current in post-weld heating step; post-weld heating step duration and the area of the interface formed between the two surfaces. Based on the available measurement instruments of the equipments, currents are represented by percentage of the heating power used in both steps. The process parameters denominated by letters are shown in Table 1. One of the important factors in UW is the current that passes from joint. Passing current from the work piece produce heat and makes the solid piece transfer to semi-solidus phase. Changing this parameter must be done in solidus phase of the element where the two work-pieces are joined together. Variation of parameters A and B, Table 1, meets this purpose. Since the voltage is constant and based on its relation with power consumption, the current value can be obtained from the consumed power.

Table 1.
Definition of parameters and machine settings

Parameter	Type of test
A	Power consumption in heating stage (%)
B	Power consumption in post-weld heating stage
C	Time of heating stage (cycles)
D	Time of post-weld heating stage (cycles)
E	Difference of cup and adaptor diameters (mm)

2.1. Variation of the process parameters

Based on technical specification of the equipments, the variation range of each parameter was designed so that operating range of the welding machine can be covered. The results are depicted in Table 2. The chosen examination method is single factor method, i.e. for each series of experiments one factor was varying while the other parameters kept constant at previously optimized levels.

Table 2.
Definition of parameters in the experiments

Parameter		Variation range in machine settings	Step
A	A1 to A14	5% to 70% (KVA)	5%
B	B1 to B14	5% to 70% (KVA)	5%
C	C1 to C14	3 to 42 (Cycle)	3 Cycle
D	D1 to D14	3 to 42 (Cycle)	3 Cycle
E	E1 to E20	9.5 to 11.5 (mm)	0.05 mm

2.2. The welding equipments and parts

Examinations were done on two parts of an oil pressure sensor shown in Figure 1. In manufacturing this part, the surfaces of the cup's undersized hole and adaptor tip have to be joined with no defect. Any defect caused by warpage of the cup surface or the weld incompleteness causes leakage and therefore results in sensor malfunction. UW is a very suitable method for joining these two parts. Both parts are low-carbon and low-alloy steel so their microstructures are perlit and ferrite phases.

The welding machine used for this work has these specifications: Microprocessor PLC controlled with a power source of 100KVA; input current: 280 A; operating voltage: 400 volts; working air pressure: 5 bars and bore of the pneumatic cylinder: 155mm. A special welding fixture was designed and fabricated as workhlding device of the operation. Zirconium-cupper alloy welding electrodes were designed to exert sufficient welding forces calculated for the operations.

For each step of every parameter three samples was manufactured; one for the test, one for repeating and reproducing the test results and the third one as a reference. Since according to Table 1 there are five parameters and each divided into fourteen steps, a total number of 225 samples were manufactured. Upon preparation of the samples execution of tensile test using an Instron^{TM} tensile test machine started. The maximum tensile load born by the weld in each sample was recorded. The rate of grippers moving is set as 30 mm/min for all tests. The test results are discussed in the next section.

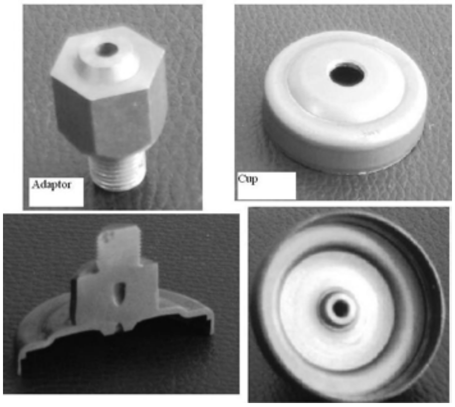

Fig. 1. The workpieces and the weldment used in the test

3. Description of results and discussion

The variations of five welding parameters that affect the tensile strength of the weld are discussed in this section. The welding parameters are: variation of power consumption in heating stage, A; variation of power consumption in post-heating stage, B; time of heating stage, C; time of post-heating stage, D and variation of cup diameter that represents contact surfaces interference, E.

3.1. Effect of power in heating stage

The effect of variation of power consumption in heating stage on tensile strength for the process conditions are displayed in Figure 2. Other process parameters are: B=15%, C=24 cycle, D=12 cycles and E=1 mm. The results show that power less than 30% of the total power is not enough to join the parts together and more heat is necessary to join them. With increasing the power usage up to 40% in the heating step, the mechanical strength of the welded area is increased. It seems that applying more heat causes a better diffusion and therefore the connection between the parts would be stronger.

3.2. Effect of power consumption in post-weld heating stage

Change in tensile strength of the weld with input power in post-weld heating stage are depicted in Figure 3. Other process parameters are: A=40%, C=24 cycles, D=12 cycles and E=1 mm.

The result shows that by increasing the power usage up to 10% the tensile strength increases considerably and then with rising the heat decreases with a mild gradient. At about 10% of power the parts weld together and results in a good tensile strength. Afterward increasing the heat will perhaps liquefy the samples and mechanical strength tends to decrease.

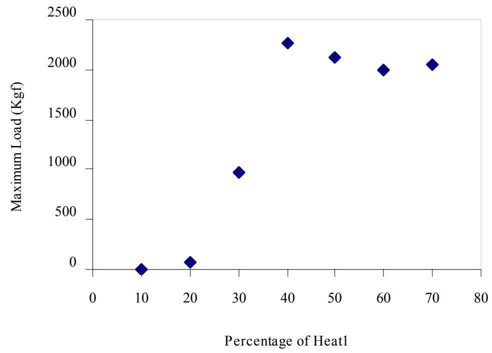

Fig. 2. Effect of variation of power consumption in heating stage on tensile strength

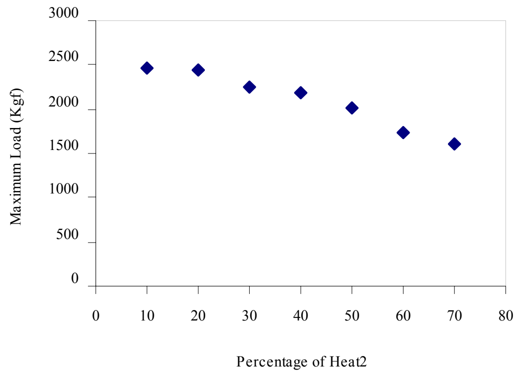

Fig. 3. Change in tensile strength with power consumption in post-weld heating stage

3.3. Effect of heating time

Observing the variation of tensile strength versus time of heating stage, not shown, with the process conditions as: A=40%, B=20%, D=12 cycle and E=1 mm, reveals that the maximum load increases with a mild gradient until the time reaches 30 cycles. Subsequently after tensile strength reaches the maximum its tendency is to become steady. Possibly grain-size growth affects the metallic bond and prevents increase in mechanical strength.

3.4. Effect of post-weld heating time

The effect of post-weld heating time on weld tensile strength with parameters as: A=40%, B=20%, D=12 cycle and E=1 mm is shown in Figure 4. The curve shows that enough time is essential to form a strong joint. With increasing this period up to 12/60 seconds the mechanical strength reaches to the highest value and then decreases.

3.5. Variation of contact surfaces interference

Effect of variation in difference of diameters of cup hole's and adaptor's tip which represnts contact surfaces interference on the maximum load was also studied. The results, not shown, indicate that with increasing the adaptor diameter and therefore interference of the abutting surfaces, mechanical strength of the joint increases. Once this interference becomes sufficient to form a joint then with increase in interference it tends to increase remarkably and become quadrupled. This can be explained by two factors: positive effect of friction on heat generation, and better plasticizing due to force. Both factors subsequently result in augmented diffusion between the joining surfaces.

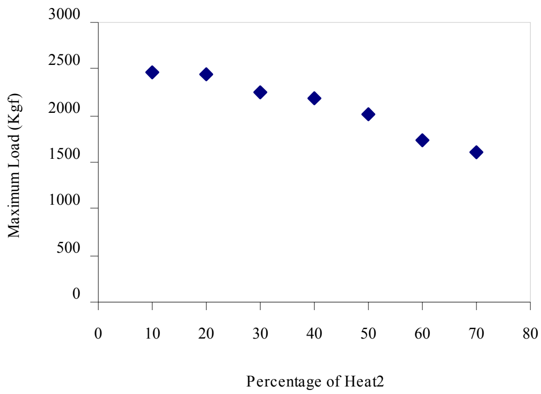

Fig. 4. Change in tensile strength with power consumption in post-weld heating stage

4. Conclusions

This paper presented the results of a study on the effect of welding parameters on the mechanical strength of the joint in UW operations. The effect of contact surfaces interference, heating and the welding joint are experimentally studied. The variation of the strength versus the process parameters was investigated by performing tensile strength tests. The results from mechanical tests show these points:

With increasing the current, mechanical strength of the joint will increase to a specific limit and then decreases with a mild gradient. Mechanical strength of the joint versus increase in the time of heating, will improve to a specific limit and then subsides and constants to a particular value. Increasing the current augments the mechanical strength of the joint to a specific limit preceding a mild decrease afterward. The effect of post-welding heat on the tensile strength is evaluated and shows that this parameter has a remarkable effect exceeding 50% improvement in tensile strength. Increase in the interface of abutting surface causes the mechanical strength of the joint to increase. The study shows the direct effect of time and current in heating stage on mechanical strength with a steeper gradient. Therefore it can be stated that these parameters have a strong effect on the UW process.

The results contribute to a better understanding of UW process. More over this paper shows significance of post-weld heating in maximum tensile strength of the weldment that needs to be noted as an important UW process parameter requiring more investigations.

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