ANALYSIS OF HEAT AFFECTED ZONE (HAZ) OF HOT AIR WELDED PVC (POLYVINYL CHLORIDE) AT DIFFERENT COMBINATION OF INPUT PARAMETERS

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Abstract*-This paper represents the results of the researches and its main purpose is to define the influence of welding parameters on the microstructure in term of grain size of Heat Affected Zone (HAZ). A comparative study was used to analyse the microstructure of welded joint by plastic welding by using hot air welding technique, under different combination of input parameter. The first combination of input parameter is made by performing the experiment in such a way that workpieces are joined at different temperature at a given certain gap distance. The second combination of input parameter is carried out by performing experiment in such a way that welding is performed at a same temperature range but for different gap distances and many more. The whole research is carried out that the information retrieved from the series of experiment is used to analyse the heat affected zone by taking photographic images of welded joint and their microstructure.*

Key Words: *Plastics, Hot gas welding, Process Parameters, Temperature, Joining, Polyvinylchloride (PVC), Welding, Hot air technique, Heating element.*

1. INTRODUCTION

Plastic welding is used for semi-finished plastic materials, and is described as a process of uniting softened surfaces of materials, generally with the aid of heat (except solvent welding). Welding of thermoplastics is accomplished in three sequential stages, namely surface preparation, application of heat and pressure, and cooling.

Numerous welding methods have been developed for the joining of semi-finished plastic materials. Based on the mechanism of heat generation at the welding interface, welding methods for thermoplastics can be classified as external and internal heating methods.

The Heat-Affected Zone (HAZ) refers to a non-melted area of metal that has experienced changes in its material properties as a result of exposure to high temperatures. The alterations in material properties are usually a result of welding or high-heat cutting procedures. The HAZ is identified as the area between the weld or cut and the base metal. These areas can vary in size and severity depending on the properties of the materials involved, the intensity and concentration of heat, and the process employed.

The thermosetting resins include phenolic resin and melamine resin, which are thermally hardened and never become soft again. Thermoplastic resins include PVC, polyethylene (PE), polystyrene (PS) and polypropylene (PP), which can be re-softened by heating.

PVC resin is often supplied in powder form and long term storage is possible since the material is resistant to oxidation and degradation. Various additives and pigments are added to PVC during the processing stage, and the blend is then converted into PVC products.

PVC is sometimes known as 'Vinyl' in Europe and predominantly so in North America. In Europe, 'Vinyl' usually refers to certain specific flexible applications, such as flooring, decorative sheets and artificial leather.

PVC is a thermoplastic made of 57% chlorine (derived from industrial grade salt) and 43% carbon (derived predominantly from oil / gas via ethylene). It is less dependent than other polymers on crude oil or natural gas, which are nonrenewable, and hence can be regarded as a natural resource saving plastic, in contrast to plastics such as PE, PP, PET and PS, which are totally dependent on oil or gas. This chlorine gives to PVC excellent fire resistance.

PVC comes in two basic forms: rigid (sometimes abbreviated as RPVC) and flexible. The rigid form of PVC is used in construction for pipe and in profile applications such as doors and windows. It is also used in making bottles, non-food packaging, and cards (such as bank or membership cards). It can be made softer and more flexible by the addition of plasticizers, the most widely used being phthalates. In this form, it is also used in plumbing, electrical cable insulation, imitation leather, signage, phonograph records, inflatable products, and many applications where it replaces rubber.

2. THEORETICAL BACKGROUNG OF HEAT AFFECTED ZONE

The Heat-Affected Zone (HAZ) is actually the area very near to fusion zone. It also suffered a change in its microstructure as heat waves also travelled through it.

The thermal diffusivity of the base material plays a large role, if the diffusivity is high, the material cooling rate is high and the HAZ is relatively small.

Alternatively, a low diffusivity leads to slower cooling and a larger HAZ. The amount of heat input during the welding process also plays an important role as well, as processes like oxyfuel welding use high heat input and increase the size of the HAZ. Processes like laser beam welding and electron beam welding give a highly concentrated, limited amount of heat, resulting in a small HAZ. Arc welding falls between these two extremes, with the individual processes varying somewhat in heat input. To calculate the heat input for arc welding procedures, the following formula is used:

$$Q = \left(\frac{VxIx60}{Sx1000} \right) x \text{ Efficiency}$$

where Q = heat input (kJ/mm), V = voltage (V), I = current (A), and S = welding speed (mm/min).

Welding processes with high rates of heat input (i.e. fast heating) have faster cooler rates compared to welding processes with low rates of heat input and thus, have smaller HAZs. Conversely, a process with low rates of heat input will result in a larger HAZ as shown in fig (a) and fig (b) The size of a HAZ also increases as the speed of the welding process decreases. the HAZ experiences sufficient heat for a long enough period of time, the layer undergoes microstructure and property changes that differ from the parent metal. These property changes are usually undesirable and ultimately serve as the weakest part of the component.

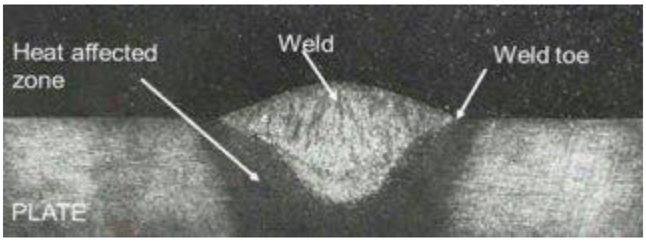


Fig (a)

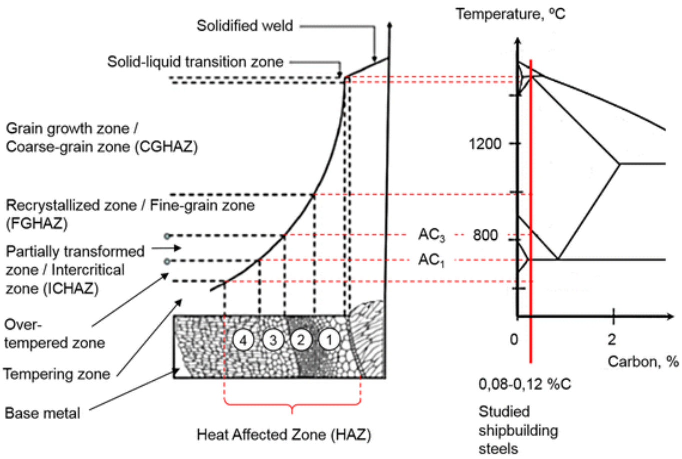


Fig (b)

3. HOT GAS WELDING

Hot gas welding, also known as hot air welding, is a plastic welding technique using heat. A specially designed heat gun, called a hot air welder, produces a jet of hot air that softens both the parts to be joined and a plastic filler rod, all of which must be of the same or a very similar plastic. (Welding PVC to acrylic is an exception to this rule.)

Hot air/gas welding is a common fabrication technique for manufacturing smaller items such as chemical tanks, water tanks, heat exchangers, and plumbing fittings.

In the case of webs and films a filler rod may not be used. Two sheets of plastic are heated via a hot gas (or a heating element) and then rolled together. This is a quick welding process and can be performed continuously.

Different types of plastics and their welding temperature

Plastics	Welding Temperature(⁰C)
ABS	350
Acrylic	350
Polyethylene	250-300
Polyisobutylene	600
PVC	220-300
Polypropylene	300
Hypalon	600
polycarbonate	350

PROCESS PARAMETER FOR HOT GAS WELDING

PROCESS PARAMETER	DESCRIPTION OF IT
Temperature	Temperature of hot gas
Gas	Composition of hot gas (air carbon dioxide, hydrogen, oxygen or nitrogen)
Angle	Include angle between weldment and rod, angle between gas nozzle and weldment.
Travel speed	Rate at which weld is being deposited
Weld force	Amount of force applied to the filler rod
Filler rod	Composition of filler rod
Pressure of hot air/gas	Pressure of gas at which it coming out from nozzle
Shoe	Design and size of welding nozzle
Gap distance	Distance between gas nozzle and workpiece
Weld joint	Butt joint and double strap fillet joint with single V groove.

4. WELDING PROCEDURE

The experimental setup should be made in such a way that the appratus is ready to use and the welding should be done in three steps:

4.1 Joint Preparation

A good homogeneous weld requires proper preparation of the material. Mild soap and lukewarm water is generally used to remove the dirt and methyl ethyl ketone is used to remove oil and grease. These foreign material may entrapped in weld bead which may leads to poor weld bead.

4.2 Heating and Pressing

A good homogeneous weld requires proper preparation of the material. Mild soap and lukewarm water is generally used to remove the dirt and methyl ethyl ketone is used to remove oil and grease. These foreign material may entrapped in weld bead which may leads to poor weld bead.

Pressure must be applied on filler rod to form close contact between the joining parts. The welding pressure is applied on the partially molten rod and ensures penetration into the weld groove

4.3 Diffusion and Cooling

Once the interfaces conform to each other, they heal together by diffusion and entanglement of molecules. Healing of the interfaces is basically the diffusion of the polymer chains across the interface from one side to the other. This mechanism is depicted at various times and degrees of healing. Under ideal conditions at complete healing, polymer chains at each side of the interface migrate cross the interface so that it essentially becomes indistinguishable from the bulk material. The final stage in the welding process is the cooling and re-solidification of the polymer at the joint. During the final step, semi-crystalline matrices re-crystalize to obtain their final micro structure. Amorphous plastics retain any orientation. In addition, thermally induced residual stresses and distortion remain “frozen” in the parts

5. RESULT AND DISCUSSION

Six identical hard PVC components were welded with above described Hot gas welding technique and their microstructure (in term of grain size) is to be examined.

The technical data of heating element is shown below. It defines the specification of the apparatus.

Table 1: Technical data of heating element

Power input	220V/50Hz
Power consumption	580W
Temperature	150^0C - 580^0C (By rotary knob adjustment)

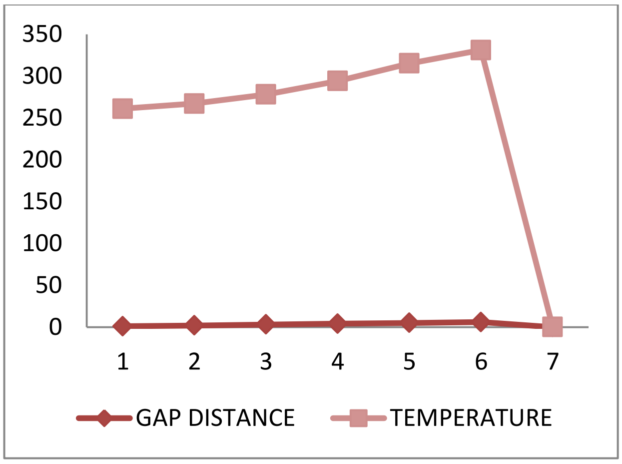
(a) The first experimental setup is to be made by handling the apparatus in such a way that the experiment is to be performed by increasing the gap distance from 1mm to 6mm (1mm, 2mm, 3mm, 4mm, 5mm, 6mm) corresponding to temperature change from 260^0C to 325^0C (260^0C 265^0C 275^0C 290^0C 310^0C 325^0C). This experimental setup is to be made to check the apparatus working and to take the appropriate gap distance with temperature.

Table 2: Process parameters for first experimental setup

Current(A)	1.8-2.2
Welding time(s)	6-15
Cooling time(s)	12-30
Dimension of workpieces(mm)	Length=20 Thickness=6

Table 3: Reading for first experimental setup

S.No	Gap Distance(mm)	Temperature (^{0}C)
1	1	260
2	2	265
3	3	275
4	4	290
5	5	310
6	6	325



Graph 1: Distribution of gap distance (mm) with temperature (^{0}C)

(b) The second experimental setup is to be made by handling the apparatus in such a way that the experiment is to be performed by taking a particular gap distance (1mm) corresponding to temperature change from 260^{0}C to 325^{0}C (260^{0}C 265^{0}C 275^{0}C 290^{0}C 310^{0}C 325^{0}C). The experimental setup is to be made for analysis purpose whose microstructure is to be shown in fig A, fig B and fig C

Table 4: **Process parameters for second experimental setup**

Current(A)	1.8-2.2
Welding time(s)	6-9
Cooling time(s)	12-15
Dimension of workpieces(mm)	Length=20 Thickness=6

Table 5: Reading for second experimental setup

S.No	Gap Distance(mm)	Temperature (^{0}C)
1	1	260
2	1	265
3	1	275
4	1	290
5	1	310
6	1	325

(c) The third experimental setup is to be made by handling the apparatus in such a way that the experiment is to be performed by taking a particular gap distance (3mm) corresponding to temperature change from 260^{0}C to 325^{0}C (260^{0}C 265^{0}C 275^{0}C 290^{0}C 310^{0}C 325^{0}C). The experimental setup is to be made for analysis purpose whose microstructure is to be shown in fig D, fig E and fig F

Table 6: **Process parameters for third experimental setup**

Current(A)	1.8-2.2
Welding time(s)	6-11
Cooling time(s)	12-17
Dimension of workpieces(mm)	Length=20 Thickness=6

Table 7: Reading for third experimental setup

S.No	Gap Distance(mm)	Temperature (^{0}C)
1	3	260
2	3	265
3	3	275
4	3	290
5	3	310
6	3	325

(d) The fourth experimental setup is to be made by handling the apparatus in such a way that the experiment is to be performed by taking a particular gap distance (5mm) corresponding to temperature change from 260^{0}C to 325^{0}C (260^{0}C 265^{0}C 275^{0}C 290^{0}C 310^{0}C 325^{0}C). The experimental setup is to be made for analysis purpose whose microstructure is to be shown in fig G, fig H and fig I

Table 8: **Process parameters for fourth experimental setup**

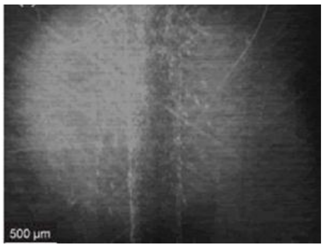
Current(A)	1.8-2.2
Welding time(s)	6-13
Cooling time(s)	12-21
Dimension of workpieces(mm)	Length=20 Thickness=6

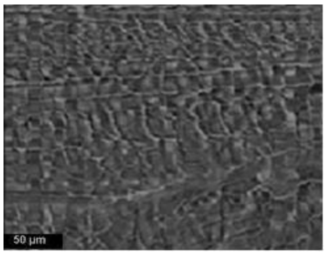
Table 9: Reading for fourth experimental setup

S.No	Gap Distance(mm)	Temperature (^{0}C)
1	5	260
2	5	265
3	5	275
4	5	290
5	5	310
6	5	325

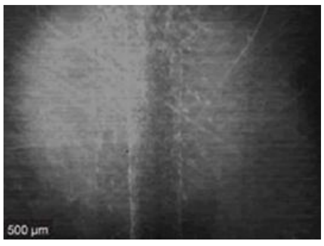
PHOTOGRAPHIC IMAGES (FIGURES) SHOWING HEAT AFFECTED ZONE (HAZ) AND THEIR MICROSTRUCTURE

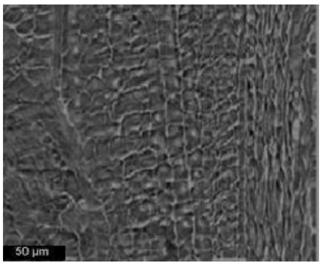
(A) For 1mm gap at 260^{0}C



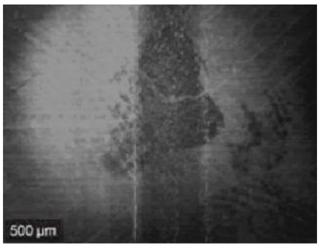


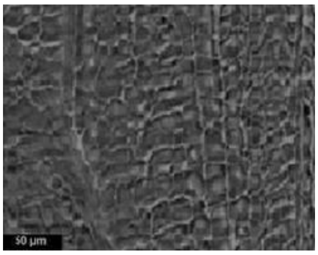
(B) For 1mm gap at 275^{0}C



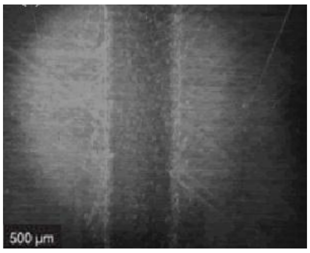


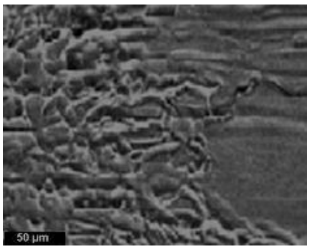
(C) For 1mm gap at 310^{0}C



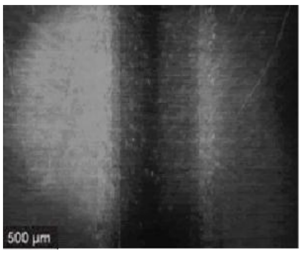


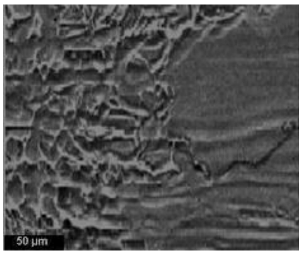
(D) For 3mm gap at 260^{0}C



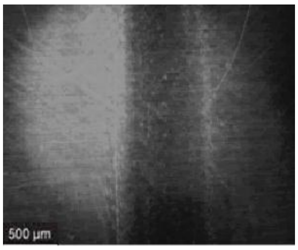


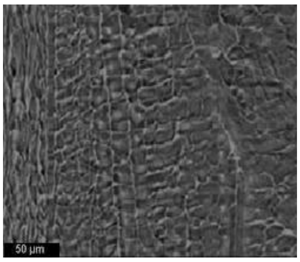
(E) For 3mm gap at 275^{0}C



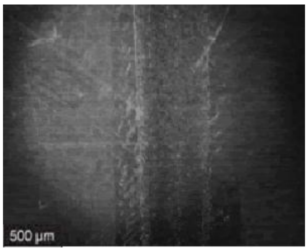


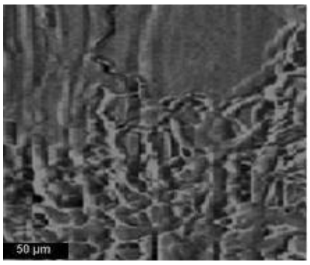
(F) For 3mm gap at 310^{0}C



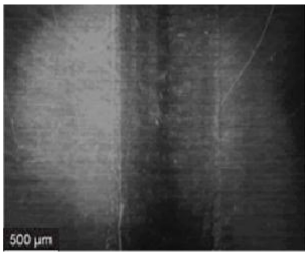


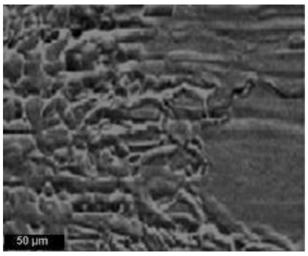
(G) For 5mm gap at 260^{0}C



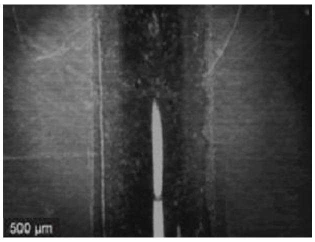


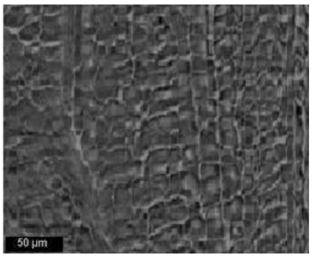
(H) For 5mm gap at 275^{0}C





(I)For 5mm gap at 310^{0}C





Air temperature depends on the type of polymer being joined, and which determines the heating elements, nozzle dimension and gas/air flow rates that are used .The melting temperature of hard polyvinyl chloride is 220 - 300ºC. And it is less important during heating if the temperature difference, not greater than 100^{0}C, between the plastic surfaces.

Generally gas used for welding is air. In hot gas (air) welding, the heat transfer medium is a heated gas, in general clean air. In the infancy of plastic welding, the use of Nitrogen proved most successful in preventing material contamination and oxidation. While direct flame chars the material (PVC) and therefore, hot gas is used for welding purpose. With today's material quality and equipment technology, Nitrogen is becoming more and more a relic of the past.

Generally angle between the filler rod and weldment is taken as 90^0 and between gas nozzle and weldment is 45^0. In a weld, exerting pressure on the molten material helps ensure through mixing of the material across the interface. Insufficient welding pressure leads to reduce weldability at the interface.

The composition of filler rod is must be similar to the polymer being welded. The filler rod has a round cross-section, but it is also available in oval, triangular and rectangular cross-section. But, standard profiles are round and triangular. Plastic welding rod does not become completely molten; it may appear much the same before and after welding. One accustomed to welding metal a plastic weld may see the weld as appearing incomplete. The reason is that only the outer surface of the rod has become molten while the inner core has remained hard.

6. CONCLUSION

From the previous result deduced, it is concluded that, on increasing gap distance on a given temperature range the HAZ increases and it has change in microstructure, it is to be determined that on increasing gap distance the Heat Affected Zone (HAZ) has microstructure changes and its grain are to be less fine as compared to gap distance of less value. Similarly, on increasing temperature for a given range of desired range of temperature, the Heat Affected Zone (HAZ) is to be less narrow. The change in microstructure is also noted, when the gap distance is to be increased, than the refinement of grain is to be less. However when the temperature is to be increased than there is more refinement of grain, it means that the microstructure has fine grain. So, there is a need for further investigation of increasing the strength of weld bead rather by changing the parameters.

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