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EFFECT OF TEMPERATURE ON MECHANICAL BEHAVIOR OF HOT AIR WELDED POLY(METHYL METHACRYLATE) (PMMA)

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Abstract— **Hot gas plastic welding is one of the easiest and cheapest welding technology for joining thermoplastics. A stream of hot gas is used to raise the temperature of workpiece because of which joining occurs. The Various input parameters such as hot gas temperature, welding speed, air flow rate etc. have effect over mechanical and morphological properties of welded joint. A lot of experiment work has been done on PVC, PE and PP. Nowadays, poly(methyl methacrylate)(PMMA) is extensively used in industries. In the present work, the study of effect of hot gas temperature on the ultimate load, deflection and weld factor of hot gas welded poly(methyl methacrylate)(PMMA) for single V-joint has been carried out. The welding is done at different temperatures as suggested in guidelines for welding thermoplastics by different manufacturers. The results shows that ultimate load, deflection and weld factor initially increases with temperature then there is decreasing behaviour.**

Index terms- **Hot gas plastic welding, hot air temperature, ultimate load, deflection and weld factor.**

I. INTRODUCTION

With the improvement in mechanical and other properties of plastics, they are founding greater use in industries. we can use mechanical fastening, adhesive joining and welding for joining plastics[1]. Generally plastics are classified as thermoset and thermoplastic. Since thermoset plastics can not be resoftened, they are joined by mechanical fastening and adhesive joining. But thermoplastics can be resoftened so they can be welded. One of the easiest and cheapest welding technique is Hot Gas welding technique[7].

In 1940, Reinhardt patented the hot gas technique in which hot gas stream is used to increase the temperature of weld groove and welding rod, so that they become tacky. Then the welding rod is pressed onto the weld groove for joining[1].

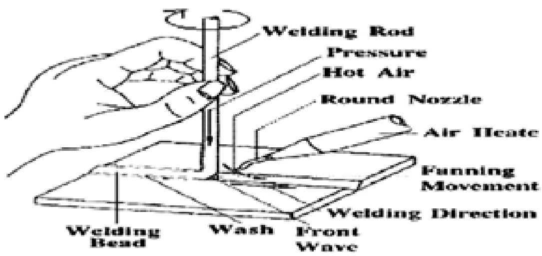

Fig .1 Schematic of hot gas welding, showing the correct position of torch and filler rod for plastic[3].

It is used in the fabrication of chemical container, sealing of roof/floor membranes for coverage, and repair of large injection moulded components. However, this method has some disadvantages such as weld quality largely depends on the operator skill [7].

Weld joint strength can be evaluated by finding the weld factor, also known as comparative weld strength ,which is expressed as

$$f_w = \sigma_{weld} / \sigma_{base} \qquad (1)$$

where σ_{weld} and σ_{base} are strengths of a weld and its base material, respectively[7].

II. LITERATURE REVIEW

Pipes of high-density PE joined by hot gas technique was studied by Diedrich and Kempe [18]. Weld factors of 0.29, 2.85 and 0.94 for hot gas welded uPVC, uPVC/calcium carbonate(15 wt%) and hot plate welded uPVC respectively for 10mm sheet was reported by Abram et al. Welding was done by using nitrogen gas instead of air at a temperature of 280°C on double V-grooves[20]. For reducing weld pores a new jig was designed by Atkinson and Turner[21]. Jig facilitates the escape of hot gas from beneath of weld easily. The effect of hot air temperature and welding pressure on mechanical properties on hot gas welded polycarbonate/polester, poly(butylenes-terephthalate) and ethylene-propylene-diene monomer(EPDM) sheets of 3mm thickness was studied by them.The weld factors of single V-welds, single V-welds with heated roller, and double V-welds (X-welds) were 0.59, 0.70, and 0.63 for the polycarbonate/polyester system, 0.76, 0.89, and 0.97 for poly(butylene − terephthalate) and 0.78, 1.00, and 0.67 for EPDM, respectively. A hot gas welding portal was designed by Marczis and Czigany to reduce the human interference on the welding parameters such as welding speed, welding force, welding temperature and flow rate of gas[22]. They reported that the tensile strength of hot gas welded PP sheets reached 19 MPa when the welding force range was 12 − 16 N. The heat-affected zone (HAZ) of welds is divided into three well-distinguishable parts, namely the cool, plastic, and flow zone of the weld centre[23]. Undercuts in the base material and on the root, incomplete and excessive fusion, pores, reinforcement on welds etc. are the different types of weld defects for hot gas, extrusion and hot plate welding as reported by Cramer[24]. Pollutants from laser cutting and hot gas welding of PP, PVC, PC, PMMA and PA6 sheets was studied by Sims et al.[25]. They performed hot gas welding for 4 h in a cabinet and obtained a simple mixture of substances in small quantities with no detectable particulate content. Md Shakibul Haque et al. studied the effect hot gas temperature, welding speed and air flow rate on the tensile strength of 5mm thick PVC sheet. They reported the maximum strength of 11.25MPa for single V-joint at a temperature of 275̊C, welding speed of 35mm/sec and air flow rate of 5.893cm^3/sec[17].

The aim of this work is to investigate the effects of hot air temperature on tensile strength of poly(methyl methacrylate)(PMMA) for single V-joint.

III. PRESENT WORK

According to available literature some work has been done on PVC, PP and PE but no work is reported for PMMA therefore PMMA is selected as workpiece material in the present work as it is widely used in industries and other applications. In order to join 5mm thick extruded sheet of PMMA, hot gas welding technique is selected. Welding rod is considered same as parent material. The physical and thermal properties are shown in figure 1and 2 respectively.

Table-1: Physical of Polymethyl methacrylate

Physical Properties	Value
Density	1.15 - 1.19 g/cm³
Water Absorption	0.3 – 2 %
Moisture Absorption at Equilibrium	0.3 - 0.33 %
Linear Mould Shrinkage	0.003 - 0.0065 cm/cm
Melt Flow	0.9 – 27 g/10 min

Table2. Thermal properties of Poly(methyl methacrylate)

Thermal Properties	Value
CTE, linear 20°C	60 - 130 μm/m.°C
CTE, linear 20°C Transverse to Flow	70 - 90 μm/m.°C
Specific Heat Capacity	1.46 - 1.47 J/g.°C
Thermal Conductivity	0.19 - 0.24 W/m.K
Maximum Service Temperature, Air	41 - 103 °C
Melting Point	130°C
Vicat Softening Point	47 - 117 °C
Glass Temperature	100 - 105 °C

A. Hot air plastic welding

Hot air plastic welding setup is used in the present work (figure 2) which consist of an air pump, regulator, thermostat, hot air gun with digital temperature indicator. Flow rate range is 0 to 20 m^3/s. Temperature can be achieved upto 600ºC. The jig is provided for clamping of workpiece in order to obtain sound weld. Experimental procedure of hot air plastic welding of PMMA is shown in figure 3.

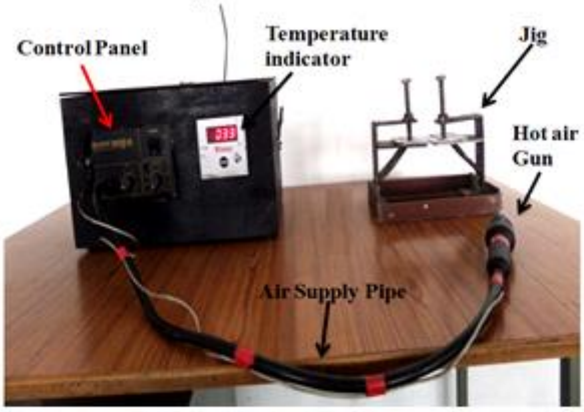

Fig .2 Hot air plastic welding setup

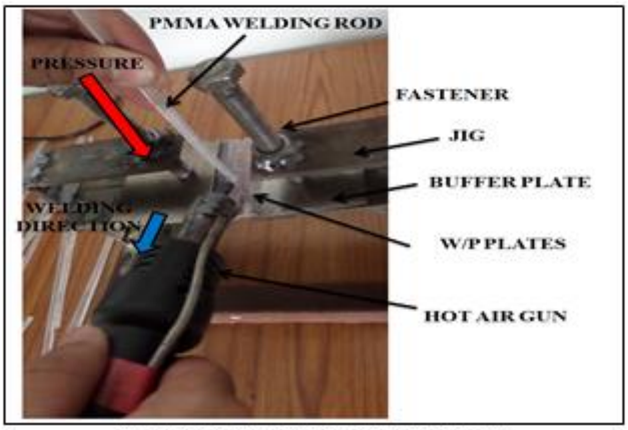

Fig .3 Hot air plastic welding experiment

B. Workpiece

The plate dimensions 80mmx60mmx5mm was selected in accordance with the jig available. The welded single V butt joint is shown in figure 4.

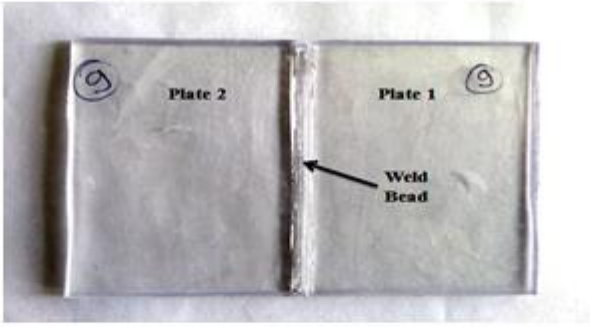

Fig .4 Hot air welded single V butt joint of PMMA sheet

IV. RESULTS & DISCUSSIONS

This section represents the results of visual inspection and tensile test followed by graphical analysis on the basis of data obtained from experimental work.

A. Visual Inspection

After the hot air plastic welding process, the welded plates undergone visual inspection and it is observed that some defects are present such as improper weld bead geometry and lack of welding rod penetration as shown in figure 5.

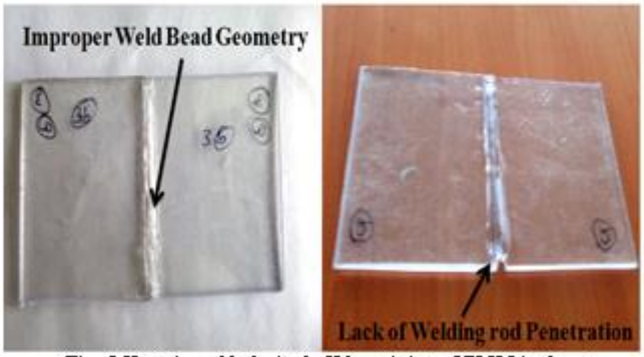

Fig .5 Hot air welded single V butt joint of PMMA sheet

B. Tensile Test

The tensile test of hot air welded joint of PMMA plates was conducted on tensile testing machine and the values of tensile load were obtained in order to plot graphs for better understanding of effect of hot air temperature on tensile load of Hot Air Welded Poly(methyl methacrylate) (PMMA) Plastic. The graphical plots are shown from figure 6 to 9. The ultimate load of parent sheet is 92.5 kgf.

Table4. Observed values of tensile load, deflection and weld factor

EXP	Hot Air Temperature ℃	Ultimate load Kgf	Deflection mm	Weld Factor
1	320	20.1	1.35	0.217
2	330	35.25	1.5	0.381
3	340	49.5	1.6	0.535
4	350	56.25	2.3	0.608
5	360	30.8	1.4	0.333
6	370	28.65	1.3	0.310

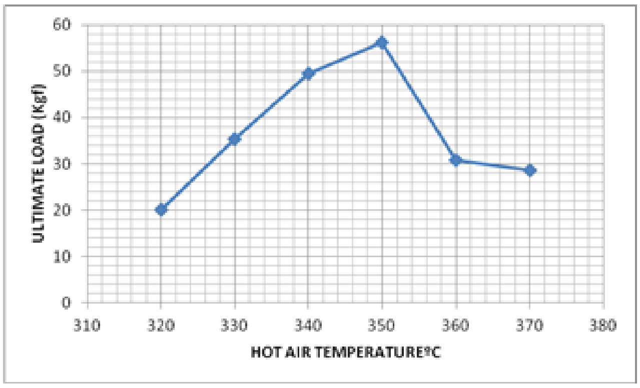

Fig .6 Graph shows the variation of **Ultimate load** of butt joint with respect to hot air temperature in plastic welding of PMMA plates

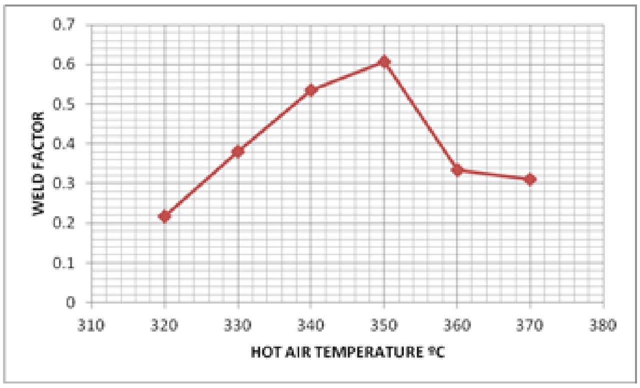

Fig .7 Graph shows the variation of **weld factor** of butt joint with respect to hot air temperature in plastic welding of PMMA plates

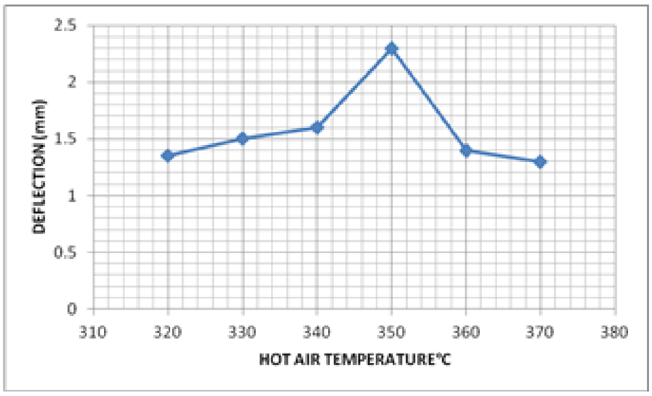

Fig .8 Graph shows the variation of **deflection** of butt joint with respect to hot air temperature in plastic welding of PMMA plates

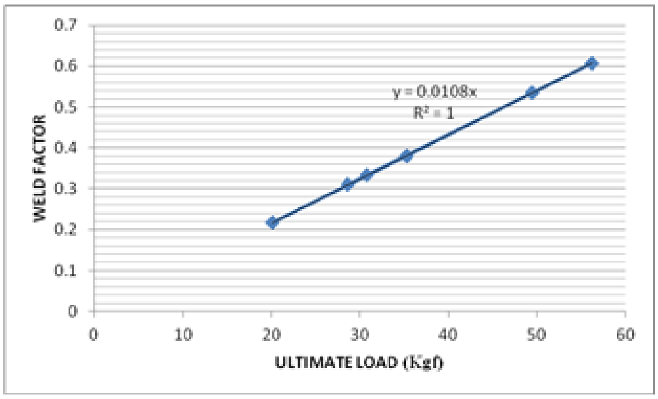

Fig .9 Graph shows the relationship of **weld factor and ultimate load** of hot air welded butt joint of PMMA plates

V. CONCLUSION

After successful hot air plastic welding of PMMA plates by using experimental setup, following conclusions can be drawn:

- Ultimate load increases with increase in hot air temperature and the maximum value is achieved at 350ºC, then there is sudden decrease upto 360ºC followed by gradual decrease from 360ºC to 370ºC.
- Weld factor increases with increase in hot air temperature and the maximum value is achieved at 350ºC, then there is sudden decrease upto 360ºC followed by gradual decrease from 360ºC to 370ºC. The pattern is similar to ultimate load.
- Deflection increases gradually upto 340ºC followed by sudden increase and the maximum value is achieved at 350ºC, then there is sudden decrease upto 360ºC followed by gradual decrease from 360ºC to 370ºC.
- Weld factor and ultimate load have a linear relationship i.e. Weld factor=0.0108 Ultimate load.

The technique of hot air plastic welding can be adopted in the present scenario of wide applications of plastics. Through this method of joining the cost of replacement of plastic components can be saved. The method is still in developing phase and more work is required in order to overcome the challenges of joining of plastics.

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