[논문] 한국태양에너지학회 논문집
Journal of the Korean Solar Energy Society
Vol. 21, No. 2, 2001

태양광선을 이용한 용접부 특성

Prasad*, 김 일수**, 성 백섭**, 김 병철***

Characteristics of Welded Zone Using Solar Energy Concentration

K.D.V. Prasad*, I.S. Kim**, B.S. Sung** and B.C. Kim***

*School of Mech.Mfg.& Med. Engineering, Queensland University of Technology
**Department of Mechanical Engineering, Mokpo National University
***Department of Mechanical Engineering, Chosun University

Abstract

In this paper the attempts made by the authors to explore the feasibility of utilising concentrated solar beam radiation for joining engineering thermoplastics such as Acrylonitrile/Butadiene/Styrene (ABS), Polycarbonate(PC) and Polymethylmethacrylate(PMMA) are presented. In addition, to study the joining of the materials, necessary experimentation with applying primer was performed. Tensile tests were conducted to determine the bond strength achieved at the specimen joint interface. Microscopic examinations of the fractured joints were performed in order to analyse the overall bond quality. Finally, the results in terms of bond strength achieved at the joint interface and energy consumed in the process were compared with those obtained with similar thermoplastic joining technique utilising microwave energy. In conclusion some advantages and limitations were outlined and necessary improvements of the jointing technique were recommended.

1. Introduction

Joining of plastic materials and their composites can be broadly divided into mechanical fastening and bonding. Bonding can be further classified into adhesive bonding, solvent bonding, and welding. Welding can be further categorised into thermal bonding, friction welding and electromagnetic bonding[1]. Some common aspects of current conventional and alternative plastic welding technologies under development are discussed in the literature[2]. While many of the above mentioned conventional plastics joining technologies have been used for years, some modern welding technologies are in fairly early stage of development. The microwave welding process uses electromagnetic interaction between the incident microwave radiation and the materials to be joined. Industrial applications for using microwave energy to join thermoplastic materials are still in research and development stage[3]. Potente et al.[4] have reported the successful use of this technique for infrared welding of glass-reinforced polymer(polyethersulfone) in very high weld strengths (weld factor = 80%+). Jones and Tailor[5] have reported a high-speed laser welding of polyethylene films using carbon dioxide and Nd-YAG lasers. Weld speeds of 50 metres/minute were achieved and higher speeds were considered possible. Weld strengths were near parent material strength. Many conventional and modern plastics joining technologies either use or are based on effects using different types of non-ionizing electromagnetic radiation. By definition, electromagnetic radiation is a form of energy(of waves and particles) produced by acceleration of electric charges[6]. Some modern plastic joining technologies use artificial source of electromagnetic radiation. Even though only about one two-billionth of this energy is intercepted by the earth, the energy that strikes the earth's atmosphere in the form of sunlight each year represents the equivalent of nearly 1,000 trillion barrels of oil sufficient to fuel the global economy thousand of times over[7-13]. In this work attempts were made to study the bonding of thermoplastics with adhesives using solar radiation. In order to study the curing behaviour necessary experiments were conducted under varying conditions of temperature, exposure time, and power.

2. Experimental Setup for the Solar Energy Concentrator

The sun has been the precursors of all life on earth. This giant nuclear fusion reactor with a diameter of 1,390,000 km and a mass of about 2.0×10^{30} kg, emits radiation at a rate of 3.8×10^{23} kW. The energy travels at a speed of 300,000 km per second and takes 8.3 minutes to reach the earth[1]. One part in two billion of the energy reaches the earth as electromagnetic radiation known as sunshine or solar energy[3]. Non-reliability is the biggest retarding factor for extensive solar

Table 1. Trend of Average Radiation Distribution Recorded Over Six Days

Day	Average Total Radiation	Average Diffuse Radiation	Average Direct Radiation
1 Cloudy Day	998.4	110.7	887.7
2 Moderately Cloudy Day	1016.5	107	909.5
3 Slightly Cloudy Day	985.5	139	846.5
4 Clear Day	1007.6	93.1	914.4
5 Clear Day	995.6	100.1	895.4
6 Clear and Hazy Day	909.7	126.7	779.7

Description of Solar Energy Concentrator Used

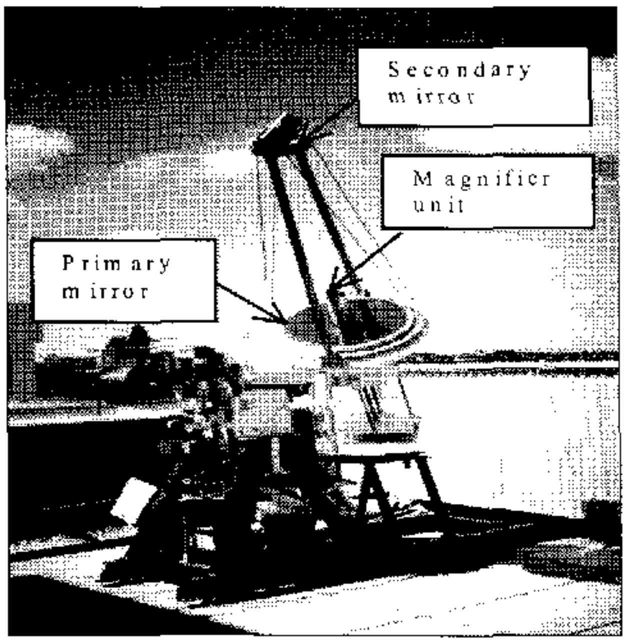

Fig. 1. Solar energy concentrator

energy utilisation. Therefore, a cost -effective solar energy system and techniques to accurately predict solar radiation should be explored. Globally, radiation has been measured for climatological studies or as a source of energy. In particular for this research, the solar radiation serves as a source of energy for curing purposes. It basically consists of three components and they are total, diffuse, and direct radiation. The average power rating measured during the six days of experiments is approximately 872.15 Watts/m^2 as shown in Table 1.

The experiments were performed with a solar energy concentrator(SEC) facility as shown in Fig. 1, which includes a small modified Cassegrainian telescope employing primary and secondary mirrors to focus the sunlight on a lens for delivering and further concentration of the light onto the specimen surface. The main component of the system is the modified two-mirror Cassegrainian telescope supported in a standard altitude-azimuth mounting. Outer diameter of the primary mirror is 600 mm and the radius of curvature is 4267 mm. It is coated with electro-plated nickel, of which reflectivity is not less than 80% in the wavelength range of 400~1200 nm. The secondary mirror has a diameter of 240 mm and radius of curvature 7433 mm. The mirror surface is enhanced aluminium coating on E3 glass substrate with grater than 80% reflectivity in the same wavelength range. This combination has an overall focal length of 2778 mm. The solar image in the Cassegrainian focus is 25 mm. To transfer the concentrated flux to the workpiece, the system is designed to use magnifying unit, canister and periscope optics and additional auxiliary optics. The initial testing experiments of the optical and thermal characteristics of the SEC facility have revealed that, the use of conventional periscope and additional auxiliary optics leads to a substantial loss of power and additional limitations on the spectral range use imposed by the optics used. For the purposes of this feasibility experiments, direct system employing a single lens has been used instead of the proposed conventional optics in order to decrease the optical and thermal losses in the system.

Solar radiation is energy originating at the sun, but only the radiation that has propagated the earth atmosphere is available for terrestrial utilisation. Before the solar radiation reaches the surface of the earth, it is absorbed, reflected, refracted, scattered and otherwise changed while it passes through the earth's atmosphere. In general, solar radiation is described as having two components, the beam(also called direct beam) radiation, and the diffuse radiation. The beam radiation comes directly from the apparent solar disc, without undergoing any reflection or refraction. The diffuse radiation is all other solar radiation falling on the surface.

In the present work, for measuring the intensity of beam insolation on the primary mirror surface, a pyranometer (type Kipp & Zonen CM6 with spectral range 0.305~2.8 μm) was used by employing two techniques. Additional collimating tube was used in the first one to filter out the scattered diffuse radiation and to allow only the direct beam radiation to enter the aperture of the sensor. In the second technique, both total and diffuse radiation were measured with the aid of the pyranometer. The amount of direct solar radiation was determined by subtracting the diffuse solar radiation from the total solar radiation.

Tensile testing of the thermoplastic materials before and after the welding process was performed using Hounsfield testing machine H10KM. Before the welding process took place five specimens of each material with dimensions 40×6×3 mm were tested. The testing speed chosen for this work was within the standard limit i.e. 5 mm per minute. From the results it was evident that among the three thermoplastic materials tested the PC could withstand the highest tensile force applied and was the most ductile material whereas the PMMA had relatively high tensile strength and was the most brittle material. The ABS had the lowest tensile strength and was relatively brittle. The average tensile strength of the ABS, PC and PMMA parent material was calculated to be 35.5MPa, 66.5MPa and 54.7MPa respectively.

Experimental work was undertaken to joint the engineering thermoplastic materials described previously by applying concentrated beam insolation. For welding to take place, 15 sets of specimens of each material were prepared. The specimen sizes and design for the tested thermoplastics were chosen accordingly to allow comparison with similar experiments performed using microwave energy. The specimens were inserted into the slot provided by means of a specimen holding device. Joining of polymers was initiated when concentrated solar beam radiation was directed onto the seam. The heat generated along the bond interface was transferred from the focal spot allocated inside to the outside surface of the test specimens, causing the specimens to soften and bond. In a similar manner, bonding of specimens was performed using priming agent such as epoxy-based resin. In this experiment the primer used was Rapid Araldite, a two-component epoxy based adhesive. After welding, the specimens were tested, and the joint microstructures were also analysed.

3. Results and discussions

The duration, power, and temperature are important parameters that control the quality of the weld. Since the quality of the weld in this experiment depends entirely on the manual skill of the welder, it is thus not possible to directly compare the weld strength achieved with each material used unless the same percentage of human error is assumed. In order to investigate the feasibility of the solar energy concentrator, the initial experiments to join thermoplastic materials by using concentrated solar radiation were performed with monitoring the welding parameters such as direct insolation, temperature at the focus point, and duration of the welding process. During the welding, due to presence of wind and clouds, the temperature was unsteady and fluctuated in the range of ±100℃. The data obtained during the initial experimentation are shown in Table 2. The tensile strength of the ABS joint ranged from 9.08 to 89.83% of the parent material strength. The tensile strength of the welded PC material ranged from 18.38 to 42.11% of the parent material strength. The percentage of parent-material strength for the welded PMMA material ranged from 4.67 to 55.23 %. The average weld strength of the ABS, PC and PMMA specimens compared to their parent material was 38.77, 27.28 and 31.76% respectively. Table 2 illustrates these results and shows that the PMMA had the slowest welding time, whereas the ABS had the fastest.

When a weld has been completed the evaluation of the quality of the joint as a rule starts with examination of the outside of the weld. The fusion of the welded specimens must be smooth and free of etching. In the welded specimens there must be no cracks, porous patches or notching, it must be regular and even. In this feasibility study the concentrated solar radiation was manually

Table 2. Average Strength of the Weld with Monitoring the Welding Parameters

Materia 1	Welding Duration (sec)	Temperature on Idle Running (℃)	Intensity of Direct Solar Radiation (W/m^2)	Wind Velocity (m/s)	Applied Tensile Force (N)	% of Parent Material Strength	Elongation (mm)
ABS	18	549	898	≤2	248	38.77	0.66
PC	27	565	922	≤2	327	27.28	0.67
PMMA	50	555	888	≤1	313	31.76	0.55

focused on the joining surface. In order to investigate whether sufficient beam energy had propagated into the specimens to promote fusion of the joint, the following section discusses the microscopic examination of the welded thermoplastic specimens, namely ABS, PC and PMMA.

Due to the manual mode of operation and ambient conditions there is significant variation in the weld strength of the tested specimens. This can be evident from Figs. 2 to 5 which show the scanning electronic microscope pictures of the welded specimens and are based on the experiments performed with monitoring the welding parameters (experiment A) and with controlling the welding duration(experiment B).

Fig. 2 shows the SEM pictures of the ABS specimens with the lowest tensile strength from experiments A and B. From this figure it can be seen that in experiment A large portion of the joint surface was not bonded which may be due to inability of the material to absorb the solar flux. Also the concent-rated insolation did not propagate enough in

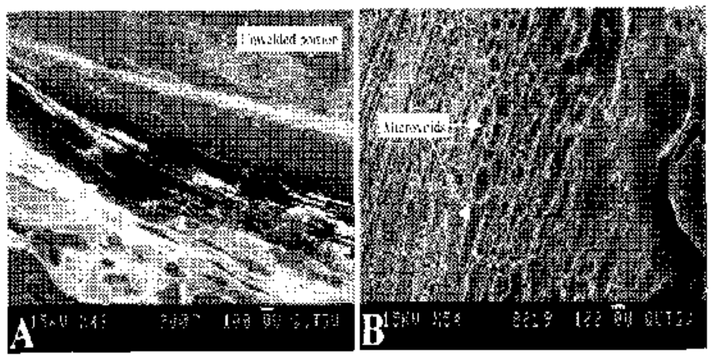

Fig. 2. ABS welding specimens with the lowest tensile strength.

the material. Fusion only took place at the surface and micro-voids were formed due to evolution of gases during the welding process. The tensile strength of weld was only 9.08 % of the parent material strength. In experiment B, micro-voids were formed at the surface of the material, reducing in size towards the bottom layer. Although a large portion was not welded, the strength of the weld increased significantly to 23.79 % of the parent material strength.

Fig. 3 shows the SEM pictures of the ABS specimens with the highest tensile strength obtained in experiments A and B. In experiment A, the highest tensile strength of 89.83 % of the parent material strength was

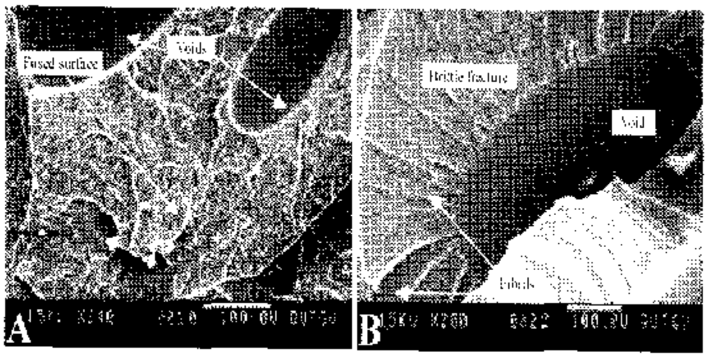

Fig. 3. ABS welding specimens with the highest tensile strength.

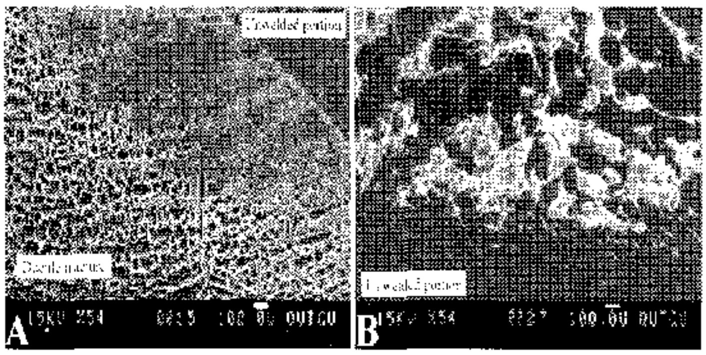

Fig. 4. PC welding specimens with the lowest tensile strength.

achieved. From the image it can be seen that the solar flux energy had propagated to the bottom layer of the material. Although voids could still be found at the surface of the material, the specimen surfaces were melted and fused together. In experiment B, weld strength of 66.98 % of the parent material strength was obtained. During the microscopic examination irregular fibrils were observed which indicated a large welded contact area. Also, the fibril direction of tear and the contours of the welded specimen were found to be similar to those of the parent material.

Fig. 4 shows the SEM pictures of the PC specimens with the lowest tensile strength from experiments A and B. For experiment A it was observed that large portion of the joint surface was not bonded, as it can be seen from the top right corner of the SEM image. When the specimen was subjected to a tensile load, the welded area ruptured leaving micro-voids and cavities due to the ductile fracture. This resulted in low tensile strength of weld of 18.38 % of the parent material strength. In experiment B, fusion took place only at the top layer of the material resulting in tensile strength of only 10.36 % of the parent material strength. The low tensile strength of the weld achieved in both experiments may be due to insufficient propagation of the concentrated solar energy flux caused by inability of the beam to cover the whole interface area.

Fig. 5 shows the SEM pictures of the PC specimens with the highest tensile strength obtained in experiments A and B. In both experiments, fusion took place at a large contact surface. Although some portion still remained unwelded, the concentrated solar energy flux propagated into the deeper layer of the material. This resulted in increase of the tensile strength to above 40 % of the parent material strength. When the specimens ruptured under the tensile test, a large number of micro-voids and cavities were formed as it can be seen from the SEM images. This may be due to insufficient absorption as this method of joining thermoplastics is based on the ability of the specimen interface to absorb the concentrated solar flux.

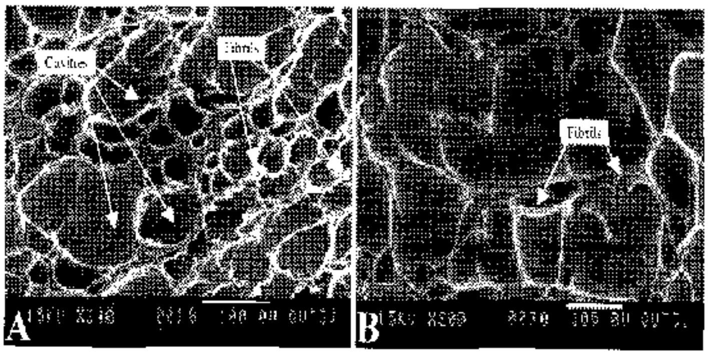

Fig. 5. PC welding specimens with the highest tensile strength.

From the experimental tests the following conclusions could be drawn. The ABS material had the fastest response to the solar radiation although it has higher glass transition temperature than the PMMA material. This is due to its opacity that allows most of the solar radiation to be absorbed and only a small amount to be reflected. PC and PMMA materials, being transparent to the visible spectra of the solar radiation absorbed less amount of direct solar radiation, most of which was transmitted through the material and some portion reflected. This resulted in melting only at the surface of the material while the bottom layer remained in its glass transition stage. As the absorptivity of thermoplastics is directly related to their opacity to the concentrated solar photons from the visual range of the spectrum, longer welding duration is required for transparent plastics. Compressive force was constantly applied to the joint of the specimens during the welding process. In the case of the PC material, this resulted in some air being trapped inside the weld. In the case of the PMMA material, air bubbles emerged from the bottom layer of the material and natural convection gradually lifted them to the surface of the material.

4. Conclusions

A feasibility study and initial experimental results of joining three different types of materials by utilising concentrated solar flux is reported. The quality of the weld could be improved should the power input remains constant and the compressive force is applied only when the whole joint is in its flow state. Solar concentrating systems seem to offer some unique opportunities for high temperature transformation of thermoplastic materials. It appears that for small-scale feasibility study and experimental demonstration of concentrated photons utilisation for materials processing a Cassegrainian solar concentrator can offer some advantages. Both incident solar radiation and the concentrated solar flux are propagating through space without being absorbed by the air. Although solar energy is considered inexhaustible resource it is diffuse compared to other sources, and intermittent and unreliable source of energy. It is largely in the visible and near-infrared regions(which is mostly collected by the SEC facility) and in general, is not directly suitable for most photo-electro chemical reactions. Additional work is already in progress to improve the tracking control by implementing a sun tracking sensor and controller for the SEC facility. Future research in the field of materials processing by utilising concentrated solar beam radiation could focus on improving the ability of transparent thermoplastics to absorb the photons from the visible spectral range, and joining of transparent and translucent or opaque to the visible solar photons thermo-plastics.

References

1. Vijay, K.S., "Polymer Engineering and Science", Vol. 29, No. 19, 1989, pp.1310~1324.
2. Stoynov, L. A. and Yarlagadda, Prasad K.D., Renewable Energy Journal , 2000, (in press).
3. Yarlagadda, Prasad K.D.V., and Tan C.C., Journal of Materials Processing Technology, Vol. 74, No. 3, 1998, pp.199~212.
4. Potente, H., Natrop, J., Pedersen, T. Klit, and Uebbing, M., "Conference Proceedings, Society of Plastics Engineers" ANTEC, May 1~5, San Francisco, pp.1274~1279, 1994.
5. Jones, I.A., and Tailor, N.S, Conference Proceedings, Society of Plastics Engineers ANTEC 94, San Francisco, May 1~5, 1994, pp.1360~1363.
6. Wagner,. J. K., "Introduction to the Solar System", Saunders College Publishing, 1991.
7. Solar 95 Renewable Energy, Conference Proceedings on 33rd Annual Meeting of ANZSES, December, 1995, pp. 3.
8. Kreith, F., and Kreider, J.F., Principle of Solar Engineering , McGraw-hill, U.S.A, 1987.
9. Winston, R., Cooke, D., Gleckman, P., and O'Gallagher, J., Proceedings of Solar '92, 1992, pp.277~281.
10 Brydson, J.A., "Plastics Materials, 5th Edition", Butterworth Heinemann, Oxford, 1989.
11. Domininghaus, H., "Plastics for Engineers: Materials, Properties, Applications", Hanser, Germany, 1988.
12. Birley, A.W., and Scott, M.J., Plastics Materials , Leonard Hill, Glasgow, 1982.
13. Gruenwald, G., "Plastics: How Structure Determines Properties", Hanser, New York, 1993.