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A study on an intelligent system to predict the tensile stress in welding using solar energy concentration

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Abstract

Plastics are now rapidly displacing conventional materials in numerous engineering applications in mass production. The emerging requirement to produce larger and more complex forms of plastics and their composites has increased the need for joining, in particular, the thermoplastics. Thermoplastics can be softened and melted on heating and hardened on cooling repeatedly without considerable degradation. Therefore, thermoplastic parts can easily be joined or formed by various manufacturing processes.

In this paper, an intelligent system for the selection of process parameters for obtaining the optimal tensile stress in welding using solar energy concentration (SEC) system is presented. To consider these quality characteristics for the selection of process parameters (solar radiation, temperature and duration), the factorial design is adopted to analyze the effect of each process parameter on the tensile stress, and then to determine the process parameters with the optimal tensile stress. The algorithms are obtained by the multiple regression technique. Finally, confirmation tests are performed to make a comparison between the results calculated from the developed system and the experimental results.

Keywords: SEC system; Multiple regression analysis; Tensile stress; Intelligent system

1. Introduction

Bonding of plastic materials and their composites can generally be classified further into adhesive bonding, solvent bonding, and welding. Of these, welding can be categorized further into thermal bonding, friction welding and electromagnetic bonding [1]. The joint formed normally has at least 90% of the parent material strength. An advantage of this process is the simplicity of the equipment. Virtually, all thermoplastics can be welded, and the process is applicable to complex joint geometry. The main disadvantage is that the process is relatively slow [2].

Friction welding includes spin, vibration and ultrasonic welding. In the spin welding process, the parts to be joined are rotationally rubbed relative to each other, under pressure, about an axis normal to the plane surface to be joined. Relative motion may be spin, continuous rotation, angular or orbital. High weld quality, simplicity and reproducibility are the main advantages of this process. However, it is suitable only for applications in which at least one of the components is circular and requires no angular alignment. In the vibration welding process, the heat necessary to melt the plastics is generated by linear motion of one of the components relative to the other while a pressure is applied between them. Once molten, the material is generated at the interface, vibration is stopped and the components are aligned. The main advantages of this process are its ability to weld large complex linear joints at a high production rate and its capability to weld a number of components simultaneously [3]. The ultrasonic welding process employs high frequency and low-amplitude mechanical vibrations to cause localized heating. The parts to be joined are held together under pressure and then subjected to ultrasonic vibration. Heat generation occurs by a combination of surface and intermolecular friction. A disadvantage of this process is that the power is not sufficient to weld large workpieces in one operation with a single machine [4]. At present, ultrasonic welding is the most widely used welding method for thermoplastics.

While many of the conventional plastics joining technologies mentioned above have been used for years, some modern welding technologies which included microwave welding, infrared heating, and laser welding are in fairly early stage of development. The microwave welding process uses electromagnetic interaction between the incident

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microwave radiation and the materials to be joined. This process depends greatly on the dielectric properties of the materials. The advantages of this process are rapid volumetric heating, no overheating at the surface, energy saving and reduced degradation. Industrial applications for using microwave energy to join thermoplastic materials are still in research and development stage [4].

The infrared heating method, being developed as a non-contact alternative to hot plate welding, uses high-intensity quartz lamps emitting 'near' infrared radiation with wavelengths around 1 mm. Usually, a parabolic mirror is used to focus the infrared radiation onto the join interface. The heating source is removed after melting has occurred, and the components are forged together. Potente et al. [5] have reported the successful use of this technique for infrared welding of glass-reinforced polymer in very high weld strengths. Another non-contact technique under development is laser welding of polymers, which promises high-speed process for welding of thermoplastics. Practically, any thermoplastic materials can be laser-welded. Jones and Tailor have reported a high-speed laser welding of polyethylene films using carbon dioxide and Nd-YAG lasers. A high weld speeds were achieved and higher speeds were considered possible.

As it can be seen from the brief overview, many conventional and modern plastic-joining technologies either use or are based on effects using different types of non-joining electromagnetic radiation [6]. By definition, electromagnetic radiation is a form of energy (of waves and particles) produced by acceleration of electric charges [7]. Electromagnetic waves are oscillating electric and magnetic fields traveling together through space at speed of light. There is an in-phase magnetic oscillation that accompanies the electric field oscillation at right angles to the electric field. The term electromagnetic radiation refers to all types of radiation that resemble light can be characterized by frequency and wavelength and these are, in order of increasing wavelength, cosmic rays, gamma rays, X-rays, ultraviolet light, visible light, infrared radiation, microwaves, and radio waves. Many of the modern plastic-joining technologies use artificial source of electromagnetic radiation. Microwaves have higher frequencies than either induction or radio frequency (dielectric) welding, and need a magnetron for generating the microwave energy. However, regardless of what type of joining technology is used, a source of electromagnetic radiation is needed, and the greatest renewable energy source available on earth is the sun.

If a material is irradiated with solar radiation, it does not necessarily mean that it has absorbed sufficient radiation. The essential attribute for the utilization of the concentrated beam solar radiation is its absorption by the irradiated material. Certain molecular arrangements can absorb certain bands of radiation. If a molecule absorbs radiation, it can be raised to an excited state, usually at one particular atom. Then, if the energy is dissipated, it may return to its unexcited or ground state and is unaffected. This is the case with longer wave radiation, which is turned into heat. However, if the radiation contains sufficient energy, it may cause a chemical reaction at the excited atom, which often leads to degradation of the material. The mechanism for absorption of photon of light in a solid involves a process called photoelectric effect in which the photon giving all its energy to an electron disappears. The photoelectric effect is responsible for the absorption of he visible light. Not all electrons meet the criteria of accepting the energy from a photon. In general, this is the reason that not all materials can accept the proton's energy [8].

There are numerous techniques developed to generate the heat required for the materials processing technology used, especially the joining process. In material processing, solar energy can serve as an alternative heat-generating source to elaborate thermally induced structural modifications. Extensive research is being dedicated to making solar energy beam applications more efficient and introducing the utilization of solar radiation into new technologies [1]. Solar concentration technologies have made considerable progress and can be applied not only to generate cost-effective electricity, but also to fulfill the energy needs in other applications for industry in general.

2. Experimental setup for the SEC system

In order to investigate the possibility of utilizing SEC for joining engineering (including transparent) thermoplastics, and to develop the intelligent algorithm, an experimental work was undertaken. The experiments were performed with an 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. The primary mirror is with outer diameter 600 mm and radius of curvature 4267 mm. It is coated with electroplated nickel with not less than 80% reflectivity in the wavelength range of 400–1200 mm. The secondary mirror has a diameter of 240 mm and radius of curvature 7433 mm. The mirror surface is enhanced aluminum coating on E3 glass substrate with greater 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 lead to a substantial loss of power and additional limitations on the spectral range use imposed by the optics used. For the purpose of this feasibility experiment, direct system employing a single lens has been