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Laser cutting of composite sandwich structures

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ABSTRACT

The paper describes a method of cutting housings of refrigerating appliances with a CO_2 laser, as a stage of their disassembly during recycling. The housings are made of laminar "sandwich" composites with low susceptibility to be processed after withdrawal from use. The problems of their utilization result from difficulties to separate the three materials making individual layers of the composite, i.e. metal, foamed polyurethane and a thermoplastic material. In the suggested method of cutting with laser beam, utilized are significant differences between melting points and flash points of these materials. Implementation of this method makes it possible to recover from waste housings sections of any shape, which could be reused with regard to their maintained insulating and mechanical properties (rigidity, compression strength).

1. Introduction

Because of increasing consumption, laws concerning collection and recycling of waste household appliances were implemented during the last decade in all the highly developed countries. These acts are aimed at promotion of recycling materials and reducing quantities of wastes intended for storage. According to the law, electrical appliances withdrawn from service are transferred from consumers to sellers, then are directed to collection points and to recycling storage areas [1,2]. Disassembly and disintegration in special appliances – shredders, are the main techniques of processing and recovering raw materials from housings of worn refrigerating units [3]. In search of an optimum way of material circulation in recycling processes, three solutions are considered:

1. The first solution is traditional recovery of raw materials from refrigerators, consisting in disassembling the compressor and transferring the rest of the refrigerator to a disintegrator. After disintegrating, a mixture of pieces of polyurethane foam, steel sheet, aluminium, plastics, copper and wire insulations is obtained. This mixture is then sorted to separate groups of materials by means of magnetic, gravitational and eddy-current methods utilizing specific properties of the materials.
2. The second solution is focused on recovering the most dangerous to environment and the most valuable components by their disassembling with minimum destructive operations. The components separated by disassembly may be passed on to further processing and reusing in industry. Residues of the housings and doors, because of their complex laminar structure, are difficult to be segregated and in this solution are transferred for storage.

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3. The third solution combines the two above-mentioned solutions and is aimed at maximum utilization of components of refrigerating appliances with no destructive operations. At the initial phase, it presumes disassembly of the components that can be easily removed from the refrigerators, like power cables, compressor, condenser and shelves. At the next phase, it is planned to utilize the housings for insulating panels by cutting-out some pieces with specific shapes. The last stage, like in the previous solution, includes destruction of all the residues in shredders, and in the final phase – segregation to material groups.

This paper concerns the second stage of the third solution, i.e. developing a technology of cutting-out shaped elements from refrigerator housings. This is a great challenge, because the housings are sandwich-type composite panels built of a metallic layer, polyurethane foam filled with gas and a solid layer of a thermoplastic. Of two alternative cutting methods, water jet and laser cutting, the first one is assessed as better with respect to versatility, cut surface quality, environmental impact and usability for cutting composites [4,5]. In terms of roughness, considering suitability of various cutting methods for cutting of AlSi–SiC composite foam, water jet cutting was also classified above laser cutting [6]. Nevertheless, laser cutting as a wear-free, nearly force-free and, above all, fast process is very attractive. Its main disadvantages like limited workpiece thickness and potentially adverse environmental impact can be minimized. This was shown in the trials of laser cutting of carbon fibre reinforced plastics (CFRP). In [7], laser remote processing with multiple parallel passes as a solution to cut CFRP materials of higher thickness was suggested. Moreover, it was shown in [8] that the environment can be adequately protected by filtering the exhaust air with a surface filter to remove aerosols and then with an activated charcoal filter to absorb VOCs (volatile organic compounds) and carbon monoxide.

In this paper, suggested is an application of laser cutting to recover shape elements from housings of refrigerators and freezers that could be reused because of their maintained insulating and mechanical (rigidity, compression strength) properties. Application of laser technology combined with traditional recycling processes has a chance to become an attractive solution in the aim to increase recovery of raw materials and reduce intermixing of the materials composing laminar structures of housings of refrigerating appliances.

At first, identification of component materials of sandwich structures used for the housings during the last 20 years was carried-out, as well as of their properties determining parameters and strategy of laser cutting, and composition of toxic gases emitted during cutting. On these grounds, the method of laser cutting was selected and its strategy was developed. Next, trials of laser cutting were carried-out and cutting parameters were optimized on the grounds of geometry and quality of cut surfaces. Effectiveness of the applied system filtering dusts and toxic gases emitted during cutting was also verified.

2. Possibility of laser cutting of laminar structures of refrigerator housings

The functions to be fulfilled by refrigerator housings as supporting structures are, first of all: ensuring rigidity to the entire appliance, ensuring thermal insulation of the interior from the environment, permitting electrical and cooling installations to be arranged inside the housing. The most appropriate for such tasks are multimaterial, laminar ''sandwich'' structures. Such a structure consists of external sheathing of steel sheet, insulation layer of foamed polyurethane and internal layer of a thermoformed polymer plastic, see Fig. 1.

Steel sheet ensures required rigidity and constructional strength, as well as protection of the insulation layer against mechanical damages. The layer of stiff polyurethane foam, filled with foaming gas, guarantees thermal insulating power, increases rigidity of the structure and permits internal installations to be sealed in it. For the internal layer, thermoformed food-grade plastics are selected, most often polystyrene (PS), polypropylene (PP) or acrylonitrile butadiene styrene (ABS) [9]. In manufacturing process of refrigerating appliances, liquid polyurethane resin is injected between two die stampings, one of steel sheet and one of plastic, where it is subjected to foaming and hardening. The above-mentioned component materials are thus permanently joined with each other and blowing gas is closed in foam cells. Therefore, material recycling of refrigerator housings and doors by disassembly is impossible. Disintegration in shredders is troublesome because of the necessity to remove the blowing agent and of ignition risk of dusts created during shredding and the blowing gas, if it is flammable [10].

2.1. *Materials for internal and external layers of composite refrigerator housings*

2.1.1. *Steel sheet*

Steel sheets make the external supporting layer of refrigerator housings and doors. These are generally black sheets of

Fig. 1 – Laminar ''sandwich'' structure of a refrigerator housing: 1 – external sheath of steel sheet, 2 – insulation layer of foamed polyurethane, 3 – internal sheath of thermoformed polymer plastic.