Comparison of apparatus and methods for tactile marking of polymeric films with Braille alphabet

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Abstract. This article analyzes contact and non-contact methods for local heat treatment of heat shrink films in tactile marking devices. The characteristics of polymeric film heating processes under heat transfer from metal stamps and laser emitters were investigated. The article contains diagrams obtained by differential scanning calorimetry of polymeric heat shrink film exposed to thermal effect of different tactile marking devices. The article also describes stereometry of Braille elements obtained by using a metal stamp and a laser emitter.

1. Introduction

The use of Braille poses great importance to visually impaired people. The number of items with tactile symbols in public places intended for visually impaired people increases every day [1]. When using Braille for reading, writing and communicating, visually impaired people face problems such as reading or answering text messages in an emergency situation [2]. This creates a need for a technology that will allow visually impaired people to use gadgets with different touch screens [3, 4]. For this purpose, smart electricity sensitive materials are used such as dielectric elastomers [5, 6], a piezoresistive touch sensor with high sensitivity and linearity [7], coil drives made of shape memory alloy (SMA) and a magnetic latch [8]. A special keyboard for smartphones allows to make smartphones fully accessible for blind people [9].

Braille is also used for tactile marking of packaging of goods and medical products in particular which have to meet additional requirements for protective marking and accurate identification of the contents. According to the requirements of the European Union, packaging must be marked in Braille and specify the name of the product, dosage information, etc. In addition to packaging marking, tactile markings are intended to help people recognize different parts, cables, hoses, pipelines and other utilities in restricted visibility conditions or in the absence of adequate illumination for technical inspection of the condition of different devices and identifying the purpose of utilities. In machine building industry, tactile marking is necessary for technical inspection of different equipment and identifying the purpose of utilities [10, 11].

The process of tactile marking of heat shrink films can be carried out by two local thermal modification methods: contact and non-contact ones. In both cases, thermal modification is achieved due to a short-term increase in temperature of small film areas (heating) under isometric conditions. These technological processes have different effect on polymeric films and different sets of technical means. Thermal modification causes a local change (decrease) in heat shrink properties of the film-forming polymer necessary for the emboss formation. The non-contact thermal modification is carried
out by using laser radiation (see figure 1a) and mechanical or vacuum devices to prevent film from shrinking when heated. The contact thermal film modification is carried out by using a special character stamp installed in a hot stamping heat press machine (see figure 1b) which, in addition to heating, has an additional function of controlling the overall film dimensions during marking.

The difference between thermal modification parameters (temperature, exposure time) used for modifying the structure of polymeric films by contact and non-contact methods causes a non-uniform distribution of heat energy through the thickness of the heat shrink film (figure 2a, b).

**Figure 1.** Fragments of machines for modifying the structure of heat shrink films. a — machine for laser thermal modification; b — character stamp for contact thermal modification. 1 — laser emitter; 2 — laser beam; 3 — mold; 4 — heat shrink film; 5 — air-permeable light-absorbing support plate; 6 — hot stamping press machine; 7 — stamp; 8 — stamp base; 9 — stamping element; 10 — bottom (cold) press plate.

**Figure 2.** Model of heat energy distribution through the film during operation of various actuators of the tactile marking device. a — laser thermal modification; b — thermal modification with a stamp. 1 — heat shrink film; 2 — area of heating up to the temperature of polymer structure modification; 3 — light-absorbing support plate; 4 — isotherms of the thermal field around the area of heating with a stamp.
Figure 2 shows the way of heating the film when using different thermal modification methods. Laser thermal modification is achieved due to the direct interaction of radiation with the film material [12] and light-absorbing support plate. When the light-absorbing support plate is exposed to the laser radiation, its temperature reaches the value necessary for modifying the structure of the shrink film areas in a split second. The heat transfer of energy from the light-absorbing support plate exceeds the energy of absorption of laser radiation by the polymer. Therefore, the isotherms of the thermal field expand in the upward radiation direction (see figure 2a).

When using a press stamp for contact thermal modification, heating of the film up to the modification temperature occurs according to the heat conduction mechanism only in the downward direction. In the center of the area of contact with the stamp, the film temperature reaches the maximum value. The film temperature decreases in the direction away from the center (see figure 2b).

Implemented on both machines processes of local thermal treatment which changes internal stresses and shrinking properties of the polymer during thermal modification differ from each other and have different effect on the result of embossed marking. In order to identify the differences, the supermolecular structure of the modified film shall be examined.

It is known [13-14] that heat shrink films, as well as all amorphous crystalline thermoplastic bodies oriented by cold drawing, "store" elastic compression energy which can be detected and measured by the differential scanning calorimetry method (DSC method). The temperature of polymer samples is heated in differential scanning calorimetry devices from the shrinkage temperature (tens of degrees below the glass transition point) to the melting temperature of crystallites and above in a free state. Meanwhile, the release of elastic compression energy is recorded by thermographs as an "exo" process, while the melting of crystallites is recorded as an "endo" process.

The objective of this work is to find the reason for the difference in the shape of Braille elements obtained using contact and non-contact tactile marking methods by investigating the thermophysical properties and supermolecular structure of the locally modified heat shrink film.

2. Subjects and methods

The subject of this study is a 50 μm thick piece of the heat shrink film made of polyethylene terephthalate [15]. The heat shrink ratio is 0.8.

DSC 204 F1 Phoenix by Netsch (Germany) was used for differential scanning calorimetry of the shrink film sample.

Two types of shrink film samples of polyethylene terephthalate with a modified structure were prepared for testing. The samples of the first type were prepared by isometric heat treatment of the film with laser radiation according to the method [10]. During radiation induced heating of films with laser radiation, the isometric state of thermal modification is achieved by the rigidity of the polymer in a glass state and the force of friction between the film and the vacuum table surface. The samples of the second type were prepared by isometric heat treatment with simultaneous compression of the film by a press stamp according to the method [11, 16].

Sets of microdisks with a diameter of 2.0 mm and a weight of 0.8-0.95 mg stamped out of polyethylene terephthalate films before and after thermal modification and placed in aluminum crucibles with a diameter of 5.0 mm with holes in the lid were prepared for calorimetric tests. Standard DSC diagrams in the coordinates "sensor signal — temperature" were obtained at 10 °C/min rate of heating of the perforated crucible.

3. Results and discussion

Figure 3 shows the diagrams of differential scanning calorimetry of original film samples, samples of the film heated up to the temperature above the melting point of crystallites (2nd melting) and two types of thermally-modified film samples in the coordinates "sensor signal — temperature".
Figure 3. Thermograms (DSC) of polyethylene terephthalate shrink films. A — the original sample (1st melting); B — the same sample (2nd melting); C — the sample after laser thermal modification; E — the sample after contact thermal modification.

The release of the elastic compression energy (shrinkage) occurs as an increase in the film temperature close to the glass transition point of polyethylene terephthalate. The specific energy of the "exo" process of releasing the elastic energy of the original film compression is 11.9 J/g. The coordinate of the maximum of the "exo" process is 103.2°C. The specific energy of melting of the crystalline part of the supermolecular structure of the original polyethylene terephthalate film is 22.2 J/g. The coordinate of the maximum of the "endo" process is 199°C.

The diagram of the reheating of the same original film sample of polyethylene terephthalate (figure 3, curve B) shows no "exo" process during the release of the elastic compression energy. This fact confirms that the film heated in a free state completely shrunk, and the structure came to an equilibrium state. As a result of heating the film up to the temperature above the melting point of polyethylene terephthalate and cooling it at 10°C/min rate, there is not enough time for its crystalline structure to recover, which is why there is no "endo" peak on the diagram of the reheating of the film.

We can see that in the sample obtained by the laser treatment (figure 3, curve C), the "exo" process occurs with a temperature shift from 90 to 152°C in comparison with the original non-thermally treated film. The specific energy of the "exo" process decreased to 10.3 ±0.5 J/g. The coordinate of the...
maximum of the process is 113.6 °C. The specific energy of the "endo" process decreased (by 10 %) to 21.7 ±0.5 J/g. The coordinate of the maximum of the process is 197.2 °C.

Thus, it is found that the laser thermal modification causes decrease in the elastic compression energy, as well as in the "endo peak" of the energy absorption during melting of crystallites, which indicates their partial melting and recrystallization [17].

The "exo" process in the sample obtained by the contact method (figure 3, curve E) shifted relative to the "exo" peak of the non-contact treatment and is in the temperature range from 95 to 160 °C. The specific energy of the "exo" process is 9.4 ±0.5 J/g. The coordinate of the maximum of the process is 108.2 °C. The specific energy of the "endo" process decreased to 14.4 ±0.5 J/g. The coordinate of the maximum of the process is 197.2 °C.

By comparing the DSC diagrams of the interval film samples prepared by using different methods of thermal modification, it can be concluded that the contact heat treatment method allows to warm up the film material more evenly, which allows to significantly reduce the elastic compression energy and is shown in the decrease in the "endo" peak.

After measuring the geometric parameters of the interval film samples with dot markings made by two actuators after total shrinkage, it was established that the height and diameter of the dots when treating the same film area are identical, while the cross section (shape) of the dots is different (see figure 4).

![Figure 4](image)

**Figure 4.** Stereometry of the embossed Braille dots. a — non-contact thermal modification; b — contact thermal modification.

The reason for such difference is the inhomogeneity of the thermal field caused by heating of the local film area during thermal modification using machines and attachments of different design. The use of a heat press machine with a character stamp for tactile marking allows the film to be heated more evenly due to the pressure applied to it, whereas when using the non-contact heat treatment, a focused laser beam is concentrated in the center of the treated area and warms up the film unevenly.

4. Conclusion

The method of heat transfer and different structural variations of devices for marking polymers in Braille significantly affect the crystalline structure of heat shrink films and the level of internal stresses in the areas of producing Braille dots. When the heat shrink film is heated by the stamp, the actuator of the marking device has a greater impact on the recrystallization of the polymer with an equal decrease in internal stresses in the areas of producing Braille dots due to the compression of the film in the press carried out simultaneously with the heat treatment, which allows to produce Braille dots of the correct spherical shape.

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