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Experimental investigation of thin films with various overprints used for packaging labels

Jarosław Szusta[a,b], Özler Karakaş[c,*], Adam Tomczyk[a,b]

[a] Bialystok University of Technology, Faculty of Mechanical Engineering, Department of Mechanics and Applied Computer Science, Wiejska 45C Str., 15-351 Białystok, Poland

[b] Masterpress S.A., Jacka Kuronia 4 Str., 15-569 Białystok, Poland

[c] Mechanical Engineering Department, Engineering Faculty, Pamukkale University, 20070 Kinikli, Denizli, Turkey

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ABSTRACT

In this study, experimental tests based on monotonic tension of specimens made from several types of heat-shrinkable films with various overprints were performed. Basic strength parameters of films were determined, such as Young's modulus, yield stress, tensile strength, and tensile strain at tensile strength. The effects of both the type of film and the type of overprint on the aforementioned parameters were studied. Earlier results of tests on similar materials, known in the literature, were referred to, and similarities and differences were pointed out. Film heat-shrinkability tests at temperatures 70, 80, 95 °C were also conducted, indicating certain patterns between the material's mechanical properties and the degree of shrinkage.

1. Introduction

Heat-shrinkable films are currently a material that is commonly used in different branches of industry for manufacturing of all types of labels, for glass, metal and plastic packaging alike (Fig. 1). An appealing label, seen by the consumer on a bottle at the store, makes goods more attractive and grabs consumers' attention. This decides the marketing success of a given product, and thus, the manufacturer's income.

Achievement of the desired visual effect depends on a series of factors, starting from the technological parameters of the film shrinking process, the shape and size of the packaging, and ending with selection of material with the proper chemical and strength properties. Familiarity with materials' characteristics makes it possible to apply the proper process parameters for overprinting on film as well as for its future shrinking on specific packaging. Selection of the proper strength parameters has a decisive impact on the film's grip strength, its proper deformation, absence of undesirable cracks, etc.

Heat-shrinkable films used in shrink sleeve technology are a subject of interest for many authors. This has been the case since the very beginning of the first applications of this type of film, i.e. since 1958, when styrene was successfully combined with synthetic rubber [1,2].

The literature contains many studies concerning tests of various properties, including mechanical properties of the films mentioned above. One can also find an extensive review of different thermoplastic, biodegradable films in terms of strength parameters in the work of Rudnik [3]. Strength tests of polymers of this type have also been described in studies by Zhang et al. [4], Zhang et al. [5], Mo et al. [6], Tserki et al. [7,8], Matzinos et al. [9], Avérous et al. [10], Wang et al. [11], Srinivasa and Tharanathan [12]. Many studies placed emphasis on one of the cheapest and commonly available materials used for labels – starch-based polymers [11,13,14,15]. It should also be noted that the method of manufacturing polymer films has a significant effect on their mechanical properties. This particularly pertains to cross-linked polymers such as PE, PP, acrylate, where the cross-linking method has a decisive influence on the aforementioned properties [16,17]. Very good mechanical properties are obtained for oriented layered polymers [18,19,20,21,22].The number of layers in materials of this type usually falls within the range of 2–7 [23]. Besides strength properties, much attention is also devoted to shaping optimal optical and visual properties [24,25].

It is difficult to find a paper that focuses on the effect of the technological process of overprinting on film and of the type of overprint on basic mechanical properties, not just the type of film. Notion of "overprint" should be understood as an effect of spreading several single ink layers which generate final pattern (color). The authors of this paper focused on testing the effect of both film type and overprint type on basic strength properties of selected film types used for "sleeve" labels.

* Corresponding author.
E-mail address: okarakas@pau.edu.tr (Ö. Karakaş).

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Fig. 1. Example packaging with labels made of heat-shrinkable film.

2. Experimental

2.1. Specimens and nomenclature

Experiments were carried out in two main steps. For the first process tests were conducted on specimens made from six different types of heat-shrinkable films most commonly used at the Masterpress S.A. plant. Nine different overprints, fixed by UV light, were applied to each film. A fragment of film remained without overprint and was only subjected to the action of UV radiation. Overprinting of the material took place by means of flexographic technology, on a 10-color machine. After each color was applied, the process of fixing it was performed by means of UV lamps. The process of overprinting specimens was performed at a speed of 100 m/min.

Specimens were cut out by means of a blanking die that was previously designed and made (Fig. 2), with the application of a manual bench press. It should be emphasized that the direction in which specimens were cut was aligned with the direction of film contraction.

Three specimens each were collected from each type of film from an area of identical overprint, and three specimens were collected from the area subjected only to UV radiation. Ultimately, 11 series × 3 specimens each were obtained for each film. Commercial designations of films and the names corresponding to them, introduced for the purposes of describing tests, are listed in table 1, and a photograph of the film and the specimens cut out from it are presented in Fig. 3. The shape and dimensions of specimens met the requirements of standard BS EN ISO 527-3[26]. It should be noted that films 1 and 2 originated from two different manufacturers. The length of the measured part of the specimen amounted to 25 mm, and its width was 6 mm (Fig. 3). The name of each series of specimens consisted of two numbers: film number and number assigned to the overprint color symbol. For example, a "9_3" designation of a series signifies that specimens were cut out from film_3 from the area overprinted with the color "9" which corresponds to color C (cyan) as indicated in Table 1.

Fig. 2. Blanking die used in the process of cutting out specimens from heat-shrinkable film.

For the purpose of heat-shrinkability tests at elevated temperatures, square specimens with dimensions of 100 × 100 mm were prepared from overprinted materials. Specimens collected from three areas of overprint for each film, i.e. the area with color number 1, 3 and 6, were used. Specimen designations were adopted according to Table 1.

2.2. Measurements and tests

2.2.1. Monotonic tensile tests

Monotonic tensile tests were conducted according to standard BS EN ISO 527-1[27]. An 84-76 Tensile Tester from Testing Machines Inc. (Fig. 4), with an electromechanical drive and a 100 lb. (45.35 kg) range, was used for this purpose.

Each of the tested films was characterized by a different thickness t. Moreover, areas with different overprints on the same film also had varying thickness. Thus, it became necessary to measure the thickness of each series of specimens. Measurements were taken at three points over the length of the specimen's measured area by means of a micrometer with accuracy to ± 0.001 mm. The result of each of the three measurements for an individual specimen of each type was then averaged and listed in Table 2.

Based on the cited standard, a strain rate of 50 mm/min was adopted. The standard recommends to set speed of testing in accordance with appropriate standards for the material concerned. In the absence of this information the speed of testing should be agreed between the interested parties in accordance with the range 1–500 mm/min [27]. Note that during preliminary tests, stress–strain curves were determined at different speeds from the mentioned test range, ie. 20 and 80 mm/min. They showed that in the tested speed range, it did not influence on the obtained values of the strength parameters.

The essential objective of tests was to determine basic strength parameters of different films bearing different overprints. These parameters include: Young's modulus (E), yield stress (σ_Y) or stress at 0.25% strain ($\sigma_{0.25}$), tensile strength (σ_M) and strain at tensile strength (ε_M).

During experiment, measurements of actual force and displacement were read from the holder of testing machine directly. The values of stress were obtained by dividing force and cross section area of the samples. Similarly strain was obtained by using displacement and initial length of the reference length. In this way nominal tensile curves were plotted. Yield stress (σ_Y) and tensile strength (σ_M) were determined according to BS EN ISO 527-1 [27] standard. Usually, extensometers are used for precise measurements of elongation. In this case it was not necessary because of the use of a specialized strength tester intended for tensile tests of thin films. Its construction and instrumentation guaranteed the measurement of displacement with high resolution 0.0001″ (0.00254 mm). These types of testing machines are successfully used in tensile test of low-strength components such as thin films, cardboards, thin wires etc. On the other hand, the use of a classical mechanical extensometer in the analyzed case would not be possible due to the very flabby (no flexural rigidity) material that is the foil. This feature makes classic extensometer impossible to be installed directly on the sample. There is indeed the possibility of using a video extensometer or more advanced systems like "Aramis". However, practice shows that in the final stretching phase of some films there is a strong deformation also in the direction perpendicular to the surface of the sample. They are usually located in several places in the form of vertical bands clearly visible on the specimen surface. In addition, it is also possible to have a cracking process of the applied paint layers. All this activities can result in the displacement of the markers not representing actual displacements in a given direction.

Each tensile test was carried out for a single final color but each final color is decomposed into one, two or more layers. The results show that the number of layers and UV exposure time affect the strength properties of the film. Each new component layer makes the film more rigid and brittle. It would seem that the increase in rigidity should