The influence of a porous sealing insert on forces and deformations occurring in a threaded connection of a polymer packaging (*Rapid Communication*)

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DOI: dx.doi.org/10.14314/polimery.2014.673

Abstract: This article presents results of the research on the influence of porous sealing insert on the selected utility indices of a threaded connection in a polymer packaging. The research was divided into two phases. The first phase concerned the screwing of the threaded connection (between parts made of two types of high density polyethylene materials) in a lab stand for testing threaded connections "Vortex-i" by Mecmesin®. In this phase the influence of the thickness of the porous sealing insert on the tightening torque and the screwing angle was determined. The second phase concerned deformation (compression) of the porous sealing insert in the threaded connection with the help of a stress-strain machine, Zwick/Roell Z030. The research allowed to determine the range of deformations that occur in a sealing element (i.e. porous insert) depending on its thickness, as well as in a polymer cap itself in the function of a tightening torque and a screwing angle.

Keywords: polymer packaging, threaded connection, polymer screw cap, porous sealing insert.

Wpływ porowatej wkładki uszczelniającej na siły i odkształcenia występujące w połączeniu gwintowym opakowania wykonanego z tworzywa polimerowego

Streszczenie: Zbadano wpływ zastosowania wkładki porowatej (uszczelniającej) na wybrane wskaźniki użytkowe połączenia gwintowego w opakowaniu polimerowym. Pracę podzielono na dwa etapy. Pierwszy polegał na prowadzeniu modelowego nakręcania połączenia gwintowego (pomiędzy częściami wykonanymi z dwu rodzajów polietylenu dużej gęstości) na stanowisku laboratoryjnym do badania połączeń gwintowych "Vortex-i" firmy Mecmesin, podczas którego określono wpływ grubości wkładki porowatej na wartość momentu dokręcającego oraz kąta nakręcenia. Etap drugi obejmował badania modelowe odkształcenia (ściskania) porowatej wkładki uszczelniającej połączenia gwintowego z wykorzystaniem maszyny wytrzymałościowej, Zwick/Roell Z030. Uzyskane wyniki umożliwiły określenie zakresu odkształceń, które pojawiają się w elemencie uszczelniającym (wkładka porowata) w zależności od jego grubości, a także odkształceń występujących w samej nakrętce, będących funkcją momentu dokręcającego i kąta dokręcenia.

Słowa kluczowe: opakowania polimerowe, połączenia gwintowe, nakrętka polimerowa, porowata wkładka uszczelniająca.

The increase in applications of polymer components in the packaging industry [1, 2] requires ongoing study of interactions between the product, the packaging and the environment, as well as the search for new materials, packaging elements and improvements in the measurement technology. The research concerning the assessment and reduction in environmental impact of the packaging, market research and planning the development of packaging industry are equally important [3, 4]. The increase also applies to the trends in use of polymer threaded closures and it is associated with new materials for their production, innovative tools (e.g. collapsible cores to form internal threads) and plastic processing machines [5, 6]. Therefore, the laboratory research and research on real objects are simultaneously carried out [7—9]. The research uses modern measurement and testing tools (e.g. method of optical registration of deformations, using 3D scanner, computer simulations that use the finite element method — CADMOULD) [10, 11]. As a result, new structures of threaded closures of polymer packaging are created (this leads to a reduction in pro-

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duction costs of processing tools) as well as new research methods and tools [12, 13]. During the research there is a constant need for continuous updating of a number of utility parameters, as described in the literature and industry publications. An example may be parameters associated with the screwing of the polymeric closures depending on their geometries (mainly diameters of caps) [14], which are too general and do not take into account the structure of threads, the remaining elements of the merger and the closing of a package.

The aim of the research was to determine the influence of a sealing insert thickness during the closing of a polymer packaging with a threaded connection on the tightening torque, the screwing angle as well as on the stress and deformations in the elements of a threaded connection (sealing insert and a cap). As we know, excessive values of a tightening torque or screwing angle may lead to deformations or cracking of a screw cap, which will subsequently damage a packaging and cause the loss of its protective functions. On the basis of the results of such experiment it will be possible to estimate the degree of deformations in the sealing insert as well as in the cap itself.

EXPERIMENTAL PART

Materials and object of the research

Material used for the screw cap was high density polyethylene (PE-HD) with trade name Hostalen GC7260 (Basell Orlen), while the container was made with the help of extrusion blow molding from PE-HD named TIPELIN 6000B (Tiszai Vegyi Kombinat Rt). The research used sealing inserts made of porous material which was low density polyethylene (PE-LD) with density of 200 kg/m^3 and thicknesses of 1.0, 1.5, 2.0 or 3.0 mm. In Table 1 the characteristics of the selected geometries of the porous sealing inserts obtained with the help of a stereoscopic microscope OPTA-TECH® and OptaView software is presented. The screw cap was obtained by injection molding from a double-cavity form. It has a single thread with the diameter of 38 mm and a 3 mm pitch. Stripping of a screw cap (i.e. a release from a mold cavity) in the injection process was performed by pushing the ring from the male mold.

T a b l e 1. The average results of measurements of cross-sections of pores for different sealing insert thicknesses

Sealing insert thickness mm	Minimal dimension of a pore mm	Maximal dimension of a pore mm	Pore cross--section perimeter mm	Pore cross--section area mm^2
1.0	0.116	0.369	0.844	0.031
1.5	0.146	0.371	0.920	0.047
2.0	0.165	0.370	0.956	0.050
3.0	0.236	0.371	1.063	0.069

Methods of testing

A test stand for screwing is presented in Fig. 1. The device is equipped with a computer programmable control panel. The tested packaging (threaded connection) is placed between the holders that keep it in the required position. A movable holder (rotational movement) is connected with the stand base and a fixed holder is coupled with the torque sensor mounted in the stand frame. Screwing of the threaded connection was performed with the speed of 20 revolutions per minute until it reached the maximum tightening torque (leap of elements of a threaded connection), depending on the increasing screwing angle.

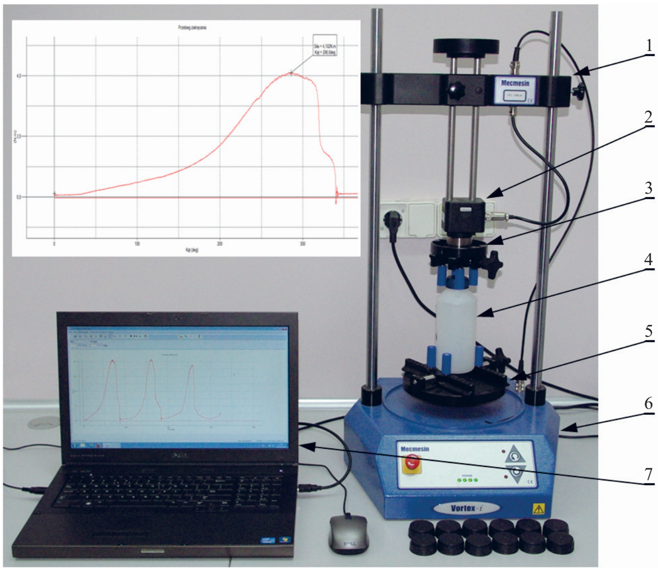

Fig. 1. The laboratory stand for testing of threaded connections of a packaging (an example of a recorded course of tightening torque of a screw cap shown in magnification): 1 — stand frame, 2 — torque sensor, 3 — fixed holder, 4 — tested threaded connection, 5 — movable holder, 6 — stand base, 7 — control computer

From the analysis of phenomena that occur in threaded connections with porous sealing inserts, complementary research was performed with the help of a testing machine. This research used an original layout of the jaws adapted to compress the sealing inserts which can approximately reproduce the scale of deformations occurring between the packaging elements in a screwing test. The test stand was presented in Fig. 2. A holder was placed between the compress plates of a testing machine (1 and 6), in which a polymer screw cap together with a sealing insert and a bushing were fixed. From the analysis of parameters of movements in screwing (conversion of the obtained rotation angle into a shift at a constant thread pitch) there was an axial displacement of the threaded connection between the elements obtained. The test elements have been designed in such a way that the

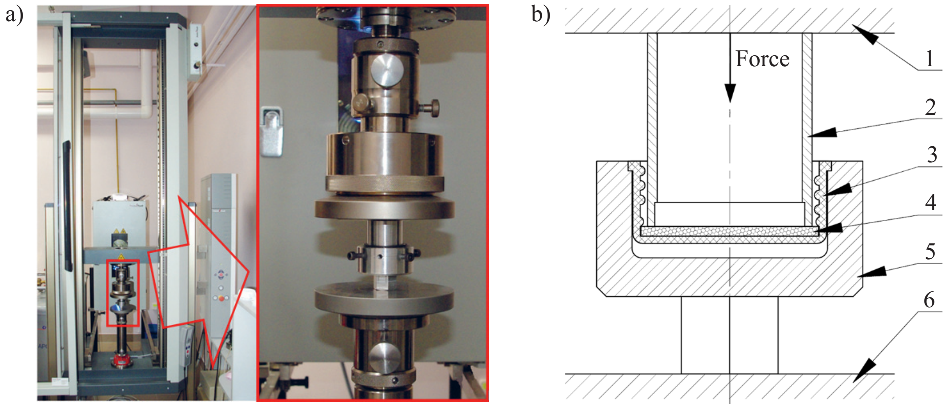

Fig. 2. Compression testing on a stress-strain machine Zwick Z030: a) testing on a stress-strain machine (the magnified image shows test stand elements), b) scheme showing invisible elements and method of testing [1 — movable compressing plate (arrow-direction of plate movement), 2 — bushing (container neck), 3 — polymer screw cap, 4 — tested sealing insert, 5 — holder of screw cap, 6 — immovable compressing plate]

screw cap bottom could deform when sealing insert was compressed, and this could additionally approximate conditions of deformation with the use of a stress-strain machine to the conditions during screwing.

RESULTS AND DISCUSSION

Fig. 3 shows exemplified courses of the tightening torque as a screwing angle function for the porous sealing inserts of varying thicknesses. An increase in the sealing insert thickness causes a deeper placing of a cap in relation to a container neck and a reduction of a tightening torque to 43 % (in the case of a sealing insert 3 mm thick) in relation to a maximum value (obtained for 1 mm thick sealing insert). Using a sealing insert of a higher thickness results in a reduction of a tightening torque.

Fig. 4 illustrates exemplary relations between the axial force and vertical displacement when compressing sealing inserts, registered in a strain-stress machine. The scope of deformations adopted in strength tests was determined on the basis of deformations obtained in the screwing test. Table 2 presents the average values of measurements in the screwing (Fig. 3) and compressing test (Fig. 4) together with the calculated values of stress when compressing the sealing insert as well as the cap tensile stresses depending on the sealing element thickness.

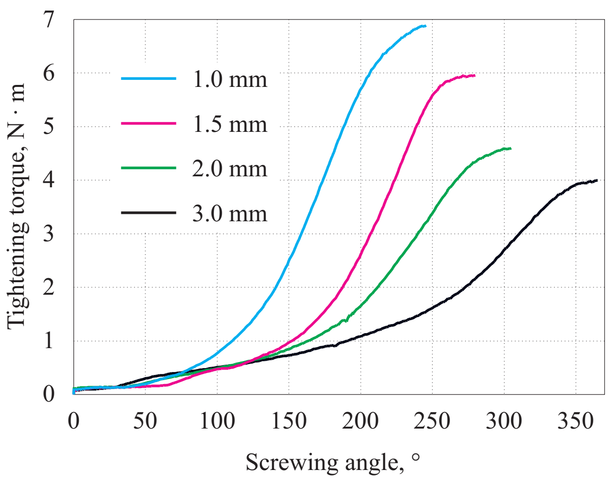

Fig. 3. The influence of the screwing angle of the screw cap on the tightening torque for different thicknesses of a sealing insert (exemplary courses)

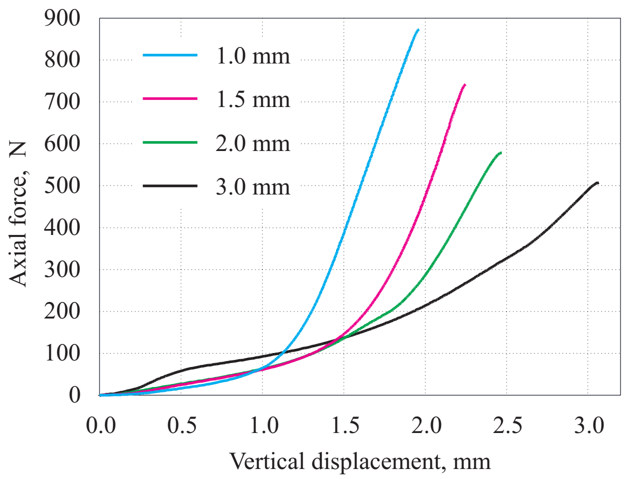

Fig. 4. The influence of vertical displacement during moving between the threaded connection elements on the axial force for different thicknesses of sealing insert (exemplary courses)

Using a thicker sealing insert leads to the increase of the screwing angle and the decrease in the maximum value of the tightening torque. The vertical displacement of a container neck in relation to the screw cap (a sum of deformation of a sealing insert and screw cap bottom) increases together with the decrease of a sealing insert thickness. This is due to a decrease of force along the vertical axis and it causes a sealing insert compression stress reduction as well as reduction in screw cap tensile stress.

T a b l e 2. The average values of investigation results of screwing, compression and the compressive stresses tests of the sealing element, as well as the cap tensile stresses for different sealing insert thicknesses

Sealing insert thickness mm	Tightening torque N · m	Screwing angle, °	Vertical displacement mm	Axial force N	Sealing insert compression stresses MPa	Screw cap tensile stresses MPa
1.0	7.02	235	1.96	971.4	19.93	23.93
1.5	6.58	269	2.24	753.5	15.46	18.56
2.0	4.56	297	2.47	586.6	12.03	14.45
3.0	3.99	365	3.04	531.4	10.90	13.09

The values of sealing insert compression stress (the surface area of a container neck which had contact with the sealing insert was accepted for calculations) and screw cap tensile stress (the surface area of cross-section of a screw cap in the cracking place was accepted for calculations here) were calculated from the elementary condition of compression and tensile strength.

Use of the sealing insert causes that a part of forces and stresses in a threaded connection is compensated by the deformation that occurs in the porous structure of the sealing insert. When compression stress acts on the sealing insert in its porous structure, the pores acquire a significant part of deformation, which as a result does not deform the screw cap bottom. Along with the increase of the sealing insert thickness, a contribution of the porous structure increases in the cross-section under research, and thus the ability to absorb the applied force as well. This is connected with the increase of dimensions (cross-section area) of individual pores. Having juxtaposed the curves shown in Fig. 3 and 4 allows giving an approximate assessment of deformation value that occurs in a screw cap, after subtracting the part for which the sealing insert is responsible for.

CONCLUSION

The research confirms that there is a constant need to verify the phenomena occurring in deformation of elements of a threaded connection of polymeric packaging, especially in the sealing insert. Using a sealing of a greater thickness causes the increase of a part of deformations that can be absorbed by the threaded connection elements, and thus reducing the stress that arises in the sensitive area of a threaded cap (a place where the side wall joins the bottom). This is extremely important in connections with closures having so-called reduced structures or technological notches (thread geometry, the catch of a sealing insert, etc.).

The research is funded by the Project „Krok w przyszłość — stypendia dla doktorantów V edycja" and co-financed by the European Union from The European Social Fund.

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Received 3 III 2014.