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RESEARCH ARTICLE

The effect of the manufacturing parameters on the surface hardness and shrinkage of polyurethane integral skin foam products

Péter Grőb
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Abstract

The effect of the manufacturing parameters on the surface hardness and shrinkage of polyurethane integral skin foam products has been investigated. Three production parameters were examined in details with the Taguchi method of experimental design, and the connection between these factors and the surface hardness were estimated by regression analysis. Furthermore the relation between the average density, as one of the key-properties of the polyurethane integral skin foam products, and the surface hardness and the shrinkage have been studied. Finally, the two time-dependent properties, the volumetric shrinkage and the surface hardness, have been investigated.

Keywords

processing technologies · industrial applications · design of experiments · polyurethane

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Péter Grőb
Department of Machine and Product Design, BME, H-1111, Műegyetem rkp.3, Budapest,, Hungary
e-mail: grob.peter@gt3.bme.hu

1 Introduction

The reaction injection moulding (RIM) is the most various and most dynamical developing technology to produce polyurethane foams [?1–3]. Despite the facts that the polyurethane foaming as an empirical technology has predominantly been based on experience for up to date, there is little information available about the real foaming process of products, about the reaction pressure generated, and about the connections among the properties of the PUR products, like surface hardness, shrinkage, average density and module of elasticity, and the manufacturing parameters.

The shrinkage is important for the mould design; the surface hardness is characteristic mechanical feature of the product, the density is a characteristic physical one. Its value is determinant for the function of the product.

The polyurethane foam products have time-dependent properties [4]. These properties come from the manufacturing method of the PUR products: the curing takes more time, then the product is in the mould, so some important physical properties value, like a surface hardness and the size, become constant just after certain time. Examining this behaviour is essential, because the standards do not give exactly the measuring time of these properties [5, 6].

Important to mention that the samples were made under industrial circumstances. Thanks to, a better descriptive model could be set, and there is a chance to discover the interactions among the manufacturing parameters.

The aim of this paper is to expose the foaming process by engineering approach, to discover the correlation between the products properties and the manufacturing parameters, and investigate the time-dependent properties of polyurethane integral skin foams.

2 Experimental

2.1 The technology of polyurethane foaming

The foaming technology of polyurethanes differs from traditional injection moulding. In general, it is termed RIM according to the English abbreviation (Reaction Injection Moulding). By RIM there are two liquid reactive components, stored separately, which are mixed with high pressure in the mixing head,

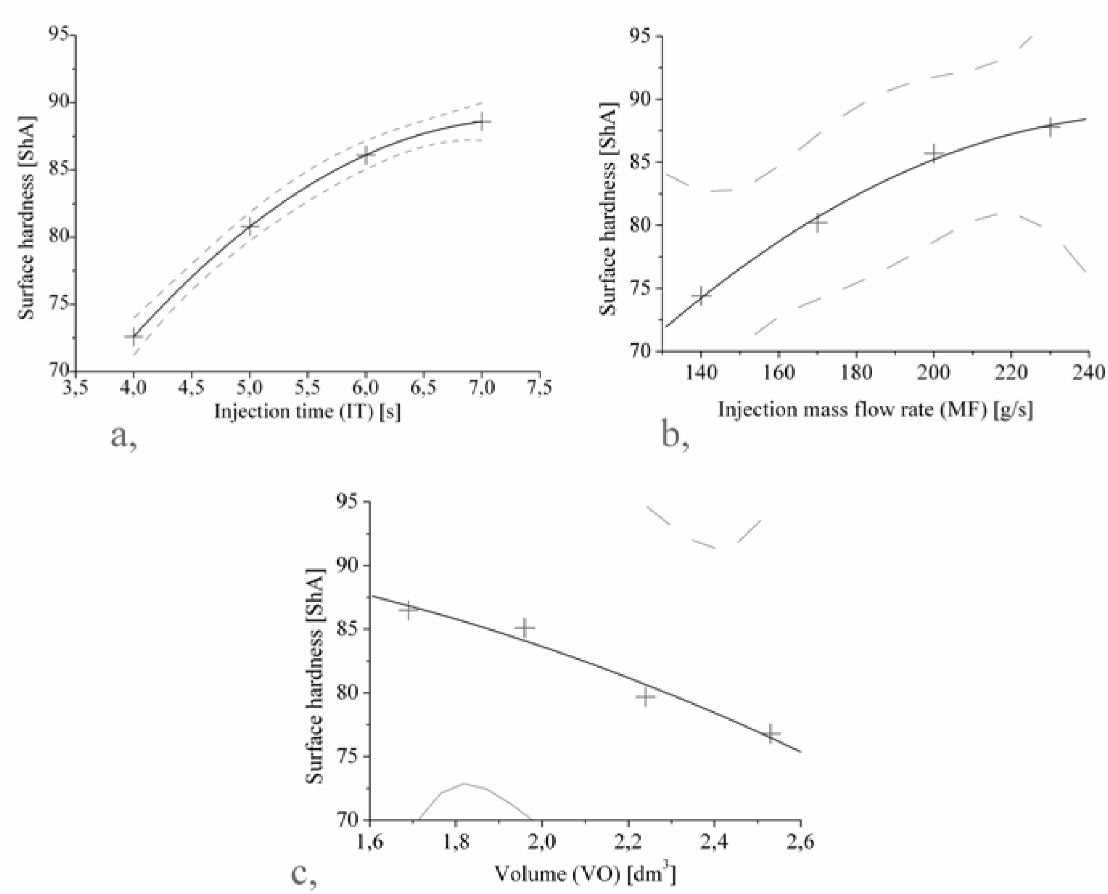

Fig. 1. The relation between the factors and the surface hardness a., relation between injection time and surface hardness b., relation between injection flow-rate and surface hardness c., relation between volume and surface hardness

and then the mixture is poured immediately into the mould. In the mould a chemical reaction starts, the liquid mixture becomes solid foam, simultaneously the foam expands, and then the curing begins as soon as the product solidifies and takes the shape required [1]-[3] .

2.2 The examined material

The tested material is the foam material ELASTOFOAM I 4703/100/schw, produced by Elastogran Kemipur Poliuretán Rendszerek Ltd. This foam system is flexible, suitable for producing integral skin foam products of 400-800 g/dm^3 density and 50-80 ShA rigidity.

2.3 The measuring methods

The surface hardness was measured according to the *ISO 7619-1:2004* standard [5] at the centre of the sample with a Zwick Roell H04.3150 type hardness tester. Shrinkage means the dimensional decrease after the moulding. It was measured according to the *ISO 2577:2007* standard [6] with a vernier calliper.

2.4 The applied design of experimental method

Three factors were investigated: the injection time (IT), the injection mass flow rate (MF) and the volume of the mould (VO). A 4-level Taguchi-design [7] was made for setting a mathematical relation between the factors and the object functions. The object functions were the surface hardness and the shrinkage. This design the factors were studied on four levels, 16 runs were made; and the interactions were not examined. The evaluation was made by the Statistica 7.0 software [8].

3 Results and discussion

3.1 Relations between the factors and the surface hardness

Mathematical relations were set between the significant factors and the surface hardness. The regression curves are shown in the Fig. 1. The crosses are the calculated points, the black line is the regression curve, and the dashed line is the confidence bound. The curves were calculated and plotted by OriginPro 7.5 software.

According to Fig. 1 the surface hardness of polyurethane integral skin foams can be calculated with the equations showed in the Table 1:

Tab. 1. The equations for surface hardness

Factors	Equation of the regression line
Injection time (BI) [s]	$ShA = 11,4 + 21(IT) - 1,4(IT)^2$
Injection flow-rate (BT) [g/s]	$ShA = 19,8 + 0,5(BT)$
Volume of the mould (TF) [dm^3]	$ShA = 91,5 + 3,6(TF) - 3,7(TF)^2$

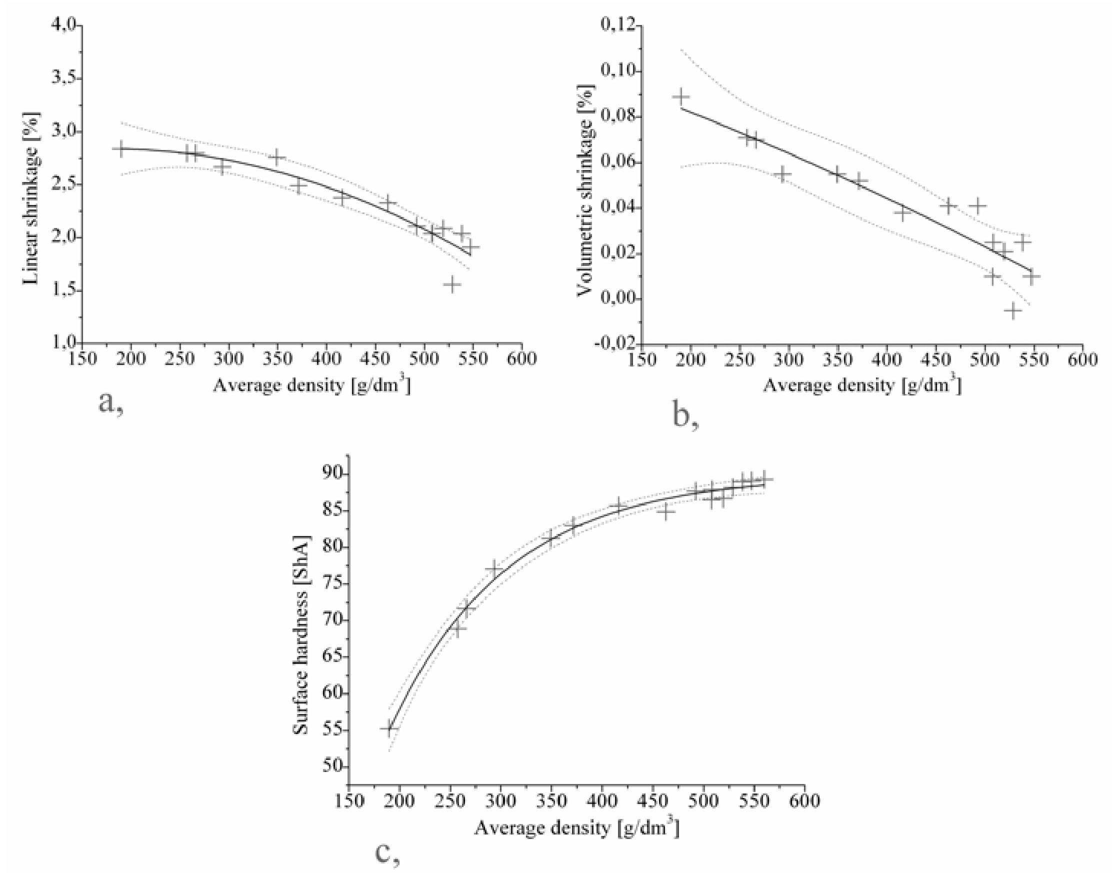

Fig. 2. The relation between the object functions and the average density a., relation between linear shrinkage and average density b., relation between volumetric shrinkage and average density c., relation between surface hardness and average density

4 Relations between the object functions and the average density

The shrinkage and the surface hardness can be determined from the average density. The average density is one of the most important properties of the polyurethane integral skin foam products. The regression curves are shown in the Fig. 2. The crosses are the measured points, the black line is the regression curve, the dashed line is the confidence bound. The curves were calculated and plotted by OriginPro 7.5 software.

According to Fig. 2 the surface hardness of polyurethane integral skin foams can be calculated with the equations showed in the Table 2.

5 Time dependence of the product properties

The surface hardness and the shrinkage are time-dependent properties of the polyurethane integral skin foams [4]. The values of the surface hardness in different time are shown in Fig. 3, and the values of the volumetric shrinkage are shown in Fig. 4. The crosses are the measured values; the continuous line is a regression curve. It was examined, from which time does not change the value of the surface hardness and the volumetric shrinkage more than 0,05% to the previous value. It can be determined, that the value of the surface hardness becomes constant after 39 hours, and the size of the product becomes constant later than 148 hours after the manufacturing.

The regression curves were calculated by OriginPro 7.5 soft-

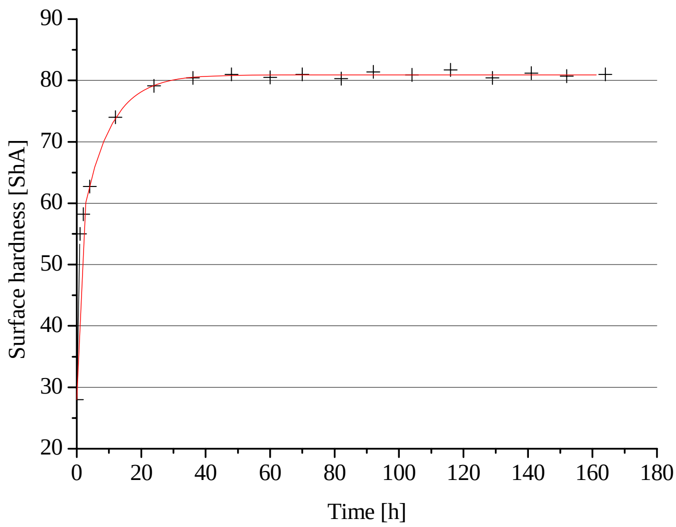

Fig. 3. The time-dependence of surface hardness

Tab. 2. The equations for object functions

Factors	Equation of the regression line
Surface hardness [ShA]	$ShA = 89,99 - 178,06 \cdot e^{\left(\frac{-\rho}{116,52}\right)}$
Volumetric shrinkage [%]	$Vol.shrinkage = 0,11 - (1,4 \cdot 10^{-4})\rho - (8,1 \cdot 10^{-8})\rho^2$
Linear shrinkage [%]	$Lin.shrinkage = 2,606 - 0,003\rho - (7,360 \cdot 10^{-6})\rho^2$

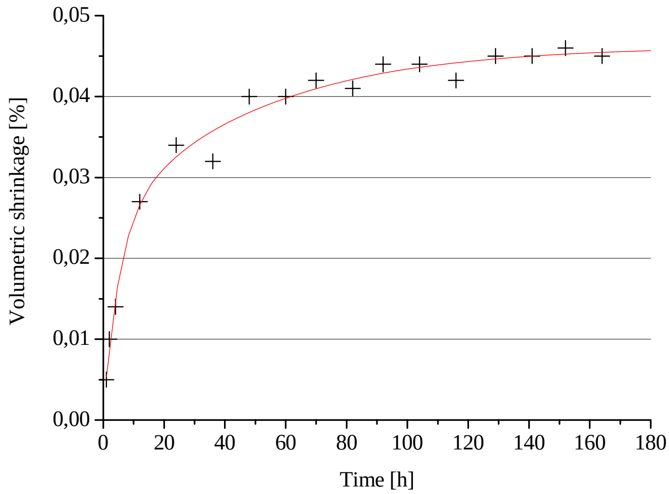

Fig. 4. The time-dependence of volumetric shrinkage

ware. According to Fig. 3 the time-dependence of surface hardness can be described with the following equation:

$$\text{Surface hardness}=80.92-24.08 \cdot e^{\left(\frac{-t}{0,22}\right)} - 28.84 \cdot e^{\left(\frac{-t}{8,54}\right)},$$

where t is the time after manufacturing. In addition, according to Fig. 4 the time-dependence of volumetric shrinkage can be described with the following equation:

$$\text{Shrinkage}=0,046 - 0,024 \cdot e^{\left(\frac{-t}{5,399}\right)} - 0,022 \cdot e^{\left(\frac{-t}{49,231}\right)},$$

where t is the time after manufacturing.

6 The application of the results

These results can be useful for the manufacturers and designers of polyurethane integral skin foams. The shrinkage can be estimated from the average density, so the appropriate mould cavity can be made. For product design the size of the shrinkage is not negligible, too. The surface hardness is the other key-parameter. If the desired value of the hardness is known, the average density and the optimal manufacturing parameters can be calculated. The consequences of the time-dependence are practical for the estimation of the time of final inspection. Furthermore, thanks to the equations the product properties can be evaluated before the time of final inspection.

7 Conclusions

The effects of the manufacturing parameters on the surface hardness and shrinkage of polyurethane integral skin foam products were investigated. The relation between the surface hardness and the three major parameters were studied, and a regression analysis was made. A correlation was established among the average density and the surface hardness and the shrinkage as well. Finally, the time-dependent properties of the polyurethane integral skin product were examined. It can be determined, that later than 39 hours after the manufacturing the value of the surface hardness and later than 148 hours the size of the product becomes constant.

References

1 **Farkas F**, *Poliuretánok*, Kémszám Bt., Budapest, 2004.

2 **Macosko C W**, *RIM fundamentals of reaction injection molding*, Hanser Publishers, Munich, 1989.

3 **Oertel G.**, *Polyurethane Handbook,* Hanser Publishers, Munich, 1994.

4 **Grőb P, Marosfalvi J**, *Integrál poliuretán hab termékek időfüggő tulajdonságainak vizsgálata*, 2008. OGÉT különszám.

5 *ISO 7619-1: Rubber, vulcanized or thermoplastic- Determination of indentation hardness- Part 1: Durometer method (Shore hardness)*, 2004.

6 *ISO 2577: Thermosetting moulding materials. Determination of shrinkage*, 2007.

7 **Roy R K**, *A primer on the Taguchi method*, Reinhold Publishing Co., New York, 1990.

8 **Marques de Sá J.P**, *Applied Statistics Using SPSS, STATISTICA, MINITAB and R*, Springer Verlag, Berlin, 2007.