

Shrinkage of Plastic Raw Materials (A Comparative Study of Mould)

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ABSTRACT- In plastic engineering, the mould design is considered a complex process or an art, due to the polymers used their differences and changes in properties, as well as other factors like shrinkage of the materials. An Important point in mould design considerations is to use real and actual values of shrinkage in the early stages of design to avoid any design errors and produce an economic template. Some containers produced locally leaks the liquids, which causes inconveniences for the users. This problem is attributed to unspecified data of raw material shrinkage. In this work, five samples made of polypropylene PP113 bought from the local market (Khartoum petrochemical company), and another five samples made of low-density polyethylene (LDPE), produced by SABIC of Saudi Arabia were moulded using ISO 294 test mould of dimension 60x60x2mm. The shrinkage for the test samples was measured according to test specifications. The averages shrinkage for samples made of PP113 was found to be 1.88, and that for LDPE was found to be 0.84. The experimental results were compared to a simulation results obtained using Visi-12.2, and MoldFlow-Mpi Ver. 5.1 software, which often used for studying and analyzing the behavior of plastic materials in moulds cavities. For Visi-12.2 software, the longitudinal shrinkage was found to amount of 1.25, for PP113 material, and 2.50 for LDPE material. For MoldFlow-Mpi Ver. 5.1 software, the longitudinal shrinkage was found to be 1.003 for PP113 material, and 2.21 for LDPE material. The study concluded that, there is a notable difference between the values of shrinkage obtained practically and that built in the software's libraries, and thus for precision parts practical shrinkage tests are inevitable.

Keywords: Keywords: Mould Design; Polypropylene - Low-density polyethylene, Shrinkage rate

المستخلص - في هندسة البلاستيك، يعتبر تصميم القالب من العمليات المعقدة او نوع من الفن وذلك لاختلاف البوليمر المستخدم والفروقات في هذه الخواص اضافة لعوامل اخرى تتدخل في العملية التصميمية مثل انكماش المواد. النقطة المهمة التي يجب وضعها في اعتبارات التصميم هي استخدام قيم حقيقية للانكماش في المراحل الاولى للتصميم وذلك لتجنب أي اخطاء تصميمية وللحصول على قالب اقتصادي. بعض الاوعية التي يتم انتاجها محلياً في مجمع ساريه السوداني تسرب السائل مما يسبب الحرج لمستخدميها وتعزى هذه المشكلة للمعطيات غير المعروفة للانكماش. في هذا العمل تمت قولبة خمسة عينات مصنوعة من متعدد البروبيلين المشتري من السوق المحلي وخمسة عينات اخرى مصنوعة من متعدد الإثيلين منخفض الكثافة من شركة سابك السعودية وذلك باستخدام قالب اختبار ايزو 294-3 نوع D2 بالأبعاد 60 x 260 x 60 ملم حيث تم قياس الانكماش حسب مواصفات ايزو. وجد ان متوسط الانكماش للعينة (PP113) هو 1.88 وللعينة (LDPE) هو 0.84 وتمت مقارنة النتائج المخبرية بنتائج محاكاة باستخدام برنامج Visi -12.2 وبرنامج MoldFlow -Mpi Ver. 5.1 المستخدمين في تحليل ودراسة سلوك المواد البلاستيكية داخل القوالب. باستخدام برنامج Visi 12.2 تم الحصول على قيمة 1.25 للانكماش الطولي للمادة وقيمة 2.5 للمادة (PP113) اما في برنامج MoldFlow -Mpi Ver. 5.1 فتم الحصول على قيمة 1.003 للانكماش الطولي للمادة وقيمة 2.21 للمادة (LDPE). خلصت الدراسة الى وجود فرق ملحوظ في قيم الانكماش المتحصل عليها عمليا وتلك المضمنة في مكتبة البرامج وبالتالي وللمنتجات الدقيقة يتحتم اجراء اختبارات عملية لقياس قيم انكماش المواد البوليميرية المستخدمة عند تصميم القوالب.

INTRODUCTION

The injection moulding technique has to meet the ever-increasing demand for high quality products, which should still be economically priced. Mould

makers and moulders face the problem of predicting or controlling the shrinkage of the plastic parts they mould. It may be difficult to understand why data are not available that are more accurate

than those published in various publications like Modern Plastics Encyclopedia ^[1]. The data normally published indicate ranges of shrinkage that can vary by over one hundred percent of the minimum. For example, published shrink data for polypropylene may indicate a shrink rate that ranges from 0.010 to 0.020 units per unit length ^[2]. Injection moulding, using almost all thermoplastics and some thermosets, can produce discrete parts that have complex and variable cross sections as well as a wide variety of surface textures and characteristics. More injection moulding machines are used for plastic processing than any other type of moulding equipment. The product quality of injection moulded plastic parts is the result of a complex combination of the material used, the part and mould designs and the process conditions used to manufacture them. If plastics are processed by injection moulding, deviation of the moulding from the dimensions of the cavity cannot be avoided. These deviations from the nominal size are summarized under the term shrinkage ^[3]. In the injection- moulding technique, shrinkage S , as explained by Equation (1), is the difference between an arbitrary dimension in the cavity and the corresponding dimension in the moulding with reference to the cavity dimension:

$$S = \frac{L_c - L_m}{L_c} * 100 \% \quad (1)$$

where: L_c : is the length of the test section of the mould cavity. L_m : is the corresponding length of the test specimen after it has cooled.

The research paper [4] reviews the factors affecting shrinkage of molded parts in injection molding. The authors used a selective screening of the papers published in the last 10 years. The reviews were organized according to molding scale (macro or micro) and by considering four branches of influence: material behaviors, processing parameters, mold, and specimen design.

Within the interval of confidence, at the macro scale, critical processing parameters were the temperatures, the packing parameters, cooling time, and injection speed; temperatures and packing parameters resulted critical factors at the micro scale as well. Concerning the design aspects, the runner size and the ribs affect shrinkage at the macro and micro scale, respectively. The analysis of the literature review has shown an absence of

statistical approach for determining the material influences, a lack of information on shrinkage occur in powder-molded parts and the absence of data in specimen with dimensions below 10 μ . The review collected the factors that affect shrinkage in injection molding, and identified three possible.

The authors ^[5] presents the results of an investigation into the effect of injection molding process parameters on the performance of direct metal laser sintered (DMLS) mold in producing quality Zytel nylon 66 plastic parts with consistency in part shrinkage and shot/part weight. The injection mold for an industrial component (hub gear) was fabricated in EOS M-250 machine using bronze- based material. The effect of four injection-molding parameters (injection pressure, melt temperature, speed, and injection time) on part shrinkage and weight were studied experimentally using L9 orthogonal array.

The weight of the part just after ejecting from the cavity, and the average shrinkage measured after cooling, were used in grey relational analysis technique to assess the effect of each molding parameter. Further, surface properties such as surface finish, wear, scratch and corrosion resistance tests were conducted on DMLS mold material samples, in order to evaluate its use in rapid manufacturing applications. The study found that injection speed and melt temperature have significant influence on part weight and shrinkage.

The optimized molding process variables were slightly more in the case of DMLS molds as compared with the parameters suggested in the plastic datasheet. Scanning electro-microscope (SEM) analysis of the mold surface after producing 5,000 glass filled Nylon 66 (Zytel) moldings did not indicate any surface degradation, confirming the use of DMLS mold in rapid manufacturing of few thousands of moldings.

Many products are made of recycled plastic and are intended to be assembled with other parts, which necessitate dimensions of controlled tolerances. This raises a need to design according to the shrinkage data, which aren't known priori. The problem of un-specified amount of shrinkage percentage causes double work for moulding design or loss of material due the inaccurate parts produced since the dimensions may be less than the needed dimension.

Problems caused by unknown amount of shrinkage can be clearly identified in assembled parts such as

urine test containers, which are composed of cups and caps. Some containers produced locally at Saria complex of Sudan leaks the liquids, which causes inconveniences for the patients. This problem is attributed to unspecified data of raw material shrinkage since these materials are purchased from the local market, and their relevant data are obtained using the Internet.

The objective of this work is compare between actual shrinkage data obtained experimentally for commercial materials or recycled plastics, and theoretical shrinkage values obtained using design software such like MoldFlow and VISI software which contains build in library of plastics such as, PP, PE, ABS...etc.

The Methodology to achieve the research objectives can be outlined as follows:

- 1.Design an injection mould using the ISO standard ISO-249-4 procedure for injection mould plastic shrinkage measurement.
- 2.Make practical samples and measure the real shrinkage.
- 3.Use design software VISI, and simulation software MouldFlow and to compare with practical results.

Standard ISO 294-4 method is used for measuring plastic shrinkage. This standard covers the measurement of specimen shrinkage for injection and compression molding.

EXPERIMENTAL WORK

Using the software program VISI and designing for the part 60*60 *2 mm the mould was designed and manufactured. The test was done by injecting the samples of the two different plastic materials, five samples for each type to get the average shrinkage. These tests were conducted at TAFRA Eng. Co. Ltd - Khartoum North.

a. Sample Preparation:

According to ISO 294 five samples of injection molded plastic of cavity dimension 60*60*2mm are prepared and measured. ISO test specifications require a conditioning period at 23° C and 50% relative humidity (RH) prior to testing to ensure that the test specimens are stabilized at the required test conditions and to provide consistency for material comparisons. The period required depends on the specific material, the test to be done, and the specifying agency.

b. Equipment used for shrinkage test:

The following equipments were used for testing:

- Injection mould
- Conditioning chamber (temp 23+-2C°and RH=50%)
- Digital Vernier caliper
- Stop watch

c. Measuring technique:

The measuring techniques shown in Figure (2).

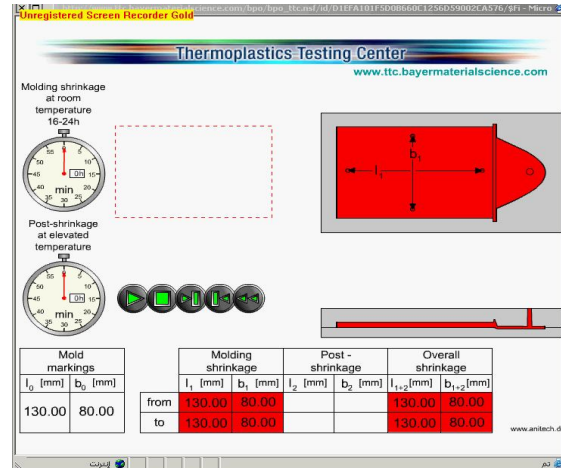


Figure 1: The Measurement techniques

d. Data of testing specimens' materials:

Two types of plastic raw materials are used to study the shrinkage and to compare the results against the available data; the first material is polypropylene PP113 which, is produced in Sudan at KPC and secondly low-density polyethylene LDPE which, produced in Saudi Arabia, at SABIC factory. Both materials have no data sheet.

e. Test procedure:

1. Prepare the mould.
2. Prepare the injection machine, the machine is operated such that the ratio of the moulding volume to the screw stroke volume is between 20 ~80% (Table 1).

TABLE 1: SHOWS THE MACHINE SPECIFICATIONS USED FOR MOULDING SAMPLES

Machine Model	Sk2500-2000H
Clamping force (ton)	2500
Screw diameter (mm)	70
Injection pressure (bar)	1940
Stroke volume (cm ³)	1040
Max injected weight (gm.)	884
Heating capacity (kw)	27.6
Screw (L/D) rate	20.5
Injection rate (cm ³ /s)	580
Plasticization capacity (g/s)	50.1

3. Prepare the plastic raw material (the raw material must be store in a dry atmosphere)
4. Mould at least five specimens.
5. Ejecting the samples.
6. Measure the shrinkage using the digital Vernier, and tabulate the results. (The shrinkage is measured within 16~24 hours after the part is injected off the mould).

RESULTS OF COMPARATIVE STUDY

Using the ISO standard, the shrinkage obtained for the tested commercial raw materials was as follows:

a. PP113 Material:

TABLE 2: AVERAGE RESULT OBTAINED FOR PP 113 MATERIAL

No	L, mm	W, mm	H, mm
1	59.21	58.92	1.90
2	59.26	58.95	1.91
3	59.20	58.85	1.91
4	59.36	59.07	1.91
5	59.27	59.01	1.91
Average	59.26	58.95	1.90

Using the shrinkage equation (1), the shrinkage percentage is obtained for PP113 as follows

Parallel shrinkage:

$$S = \frac{60 - 59.26}{60} * 100 = 1.88\%$$

Perpendicular Shrinkage:

$$S = \frac{60 - 58.95}{60} * 100 = 1.72\%$$

TABLE 3: COMPARISON BETWEEN EXPERIMENTAL AND SOFTWARE RESULTS OBTAINED FOR PP113 MATERIAL

Source	Parallel Shrinkage	Perpendicular shrinkage	Cavity length	Cavity width
Visi – software	1.25	1.25	60.75	60.75
Mpi- software	1.003	1.067	60.60	60.64
Test	1.88	1.72	61.13	61.03

TABLE 4: COMPARISON BETWEEN EXPERIMENTAL AND SOFTWARE RESULTS OBTAINED FOR PP113 MATERIAL

PP113	Cavity length (mm)	Cavity width (mm)	Cavity depth (mm)
Nominal	60	60	2
Visi Shrinkage (1.25%)	59.25	59.25	1.97
Mpi- shrinkage Parallel (1.003%) Perpendicular (1.067%)	58.3982	59.3598	1.9793
Test	59.26	58.95	1.90

b. LDPE material

TABLE 5: THE AVERAGE SHRINKAGE OBTAINED FOR LDPE.

No	L, mm	W, mm	H, mm
1	59.30	59.58	1.97
2	59.31	59.67	1.97
3	59.29	59.86	1.97
4	59.30	59.62	1.97
5	59.30	59.72	1.97
Average	59.30	59.69	1.97

Parallel shrinkage:

$$S = \frac{60 - 59.30}{60} * 100 = 0.8$$

Perpendicular Shrinkage

$$S = \frac{60 - 59.69}{60} * 100 = 0.63\%$$

TABLE 6: COMPARISON BETWEEN EXPERIMENTAL AND SOFTWARE RESULTS OBTAINED FOR LDPE MATERIAL

Source	Parallel Shrinkage	Perpendicular shrinkage	Cavity length	Cavity width
Visi – software	2.5	2.5	61.50	61.50
Mpi- software	2.211	2.007	61.32	61.20
Test	0.84	0.63	60.50	60.37

TABLE 7: COMPARISON BETWEEN EXPERIMENTAL AND SOFTWARE RESULTS OBTAINED FOR LDPE MATERIAL

LDPE 2.5%	Cavity length (mm)	Cavity width (mm)	Cavity depth (mm)
Nominal	60	60	2
Visi Shrinkage (2.5%)	58.5	58.5	1.95
Mpi- shrinkage Parallel (2.211%) Perpendicular (2.007%)	58.6734	58.7958	1.9578
Test	59.30	59.69	1.97

According to the material used in the study (samples), the real shrinkage values (obtained by practical experiments) are more accurate and highly reliable in mold design. The standard values for shrinkage of polymeric materials, which installed by simulations in the library of specialized software, always, need to be checked by using experimental approaches.

It is confirmed that, based on the obtained results, the plastic materials shrinkage obtained in the laboratory are relatively accurate and suitable for use in the design of moulds used in the injection molding, compared to those derived from the software databases and those given in the factory catalogues.

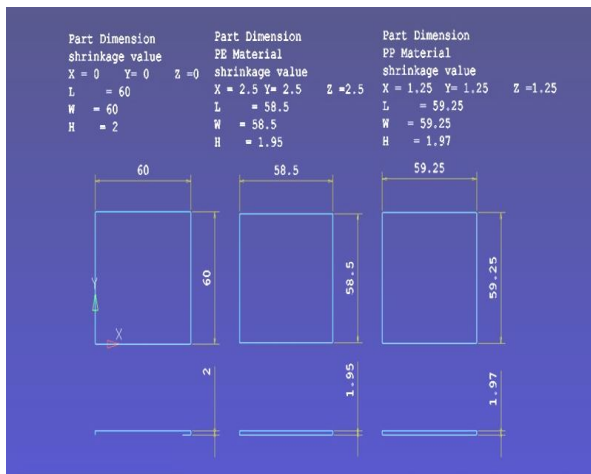


Figure 2: The result obtained by VISI software for PP113 and LDPE materials

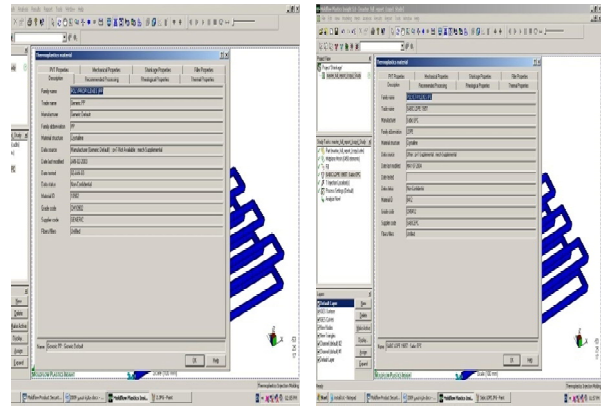


Figure 3: The result obtained by MoldFlow software for (a) PP113 and (b) LDPE materials

The study results indicate that, one of the most important design considerations is the use of real values of shrinkage in the initial stages of design to avoid design errors and to obtain a suitable template, accurate and economical. Moreover, the results need to be subjected to a statistical approach for more Conformity and more reliability.

CONCLUSION

According to the test, results obtained by making samples according to the ISO- STANDARDS the result that the data written in the textbooks or obtained from the soft ware’s libraries gives only the range not the specified and actual figure of the plastic shrinkage, for the precision parts, it should be tested practically. The tests done shows that there is measurable difference between the shrinkage obtained practically and that built in the software.

RECOMMENDATIONS

It is clear that the ISO standards does not take into account the effect of cooling, additives and fillers problems ,all these factors have their own influence on the shrinkage behavior, it is recommended that research to be continued to predict the perfect shrinkage factors.

It is recommended also for the plastic and mould designers to test the material before designing the parts or the moulds or to get the data of the plastic properties including the shrinkage data direct from the supplier.

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