

# Shrinkage Rate Measurement and Compensation Exercise for Injection Molding of Polymers Lab

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## Introduction

As part of your *Injection Molding of Polymers* lab, you must determine the shrinkage rate of different polymers that are commonly injection molded into parts in the AML. In manufacturing processes, materials that undergo a phase change (i.e. from liquid to solid) involve a decrease in specific volume and a resulting shrinkage. A certain amount of shrinkage is inevitable in any process that involves cooling of plastic from elevated temperature and this is certainly the case with injection molded polymers.

## Volumetric and Linear Shrinkage

Assuming perfectly isotropic shrinkage, the total volumetric shrinkage rate  $S_v$  of material is related to the linear shrinkage rate  $S$  by the expression

$$S = 1 - (1 - S_v)^{\frac{1}{3}} \quad (1)$$

An often-used simplification of this relationship, based on neglecting higher order terms of the binomial theorem expansion of  $(1 - S)^{\frac{1}{3}}$ , is  $S \approx \frac{S_v}{3}$ . (2)

Hence, a material exhibiting 3% volumetric shrinkage should be undersize in all directions by 1.01% after cooling. Determining a single shrinkage compensation factor using either equations 1 or 2 is suitable for most applications you will encounter in AML.

## Shrinkage Compensation

To compensate for shrinkage, the cavity dimensions of an injection mold must be made larger than the specified part dimension. The dimension of the cavity is then:

$$D_c = D_p + D_p S + D_p S^2 \quad (3)$$

where:  $D_c$  = dimension of cavity,  $D_p$  = molded part dimension, and  $S$  = linear shrinkage value for molded material. The  $S^2$  term corrects for shrinkage that occurs in the shrinkage.

For example, if the length of an injection molded polypropylene part is 5.0 inches, the corresponding cavity dimension using equation 3 and assuming a linear shrinkage value of 1.0% is 5.051 inches.

## Experimentally Determining Shrinkage Values for Polymers

Even though shrinkage rates are available for a wide range of plastics, the reported values are usually given as a range. Shrinkage can vary based on material, processing, part geometry, etc. Furthermore, shrinkage may vary in the direction of flow versus transverse direction (anisotropic shrinkage). For example, Table 1 shows typical shrinkage rates for different polymers from the GE Polymerland website<sup>1</sup>.

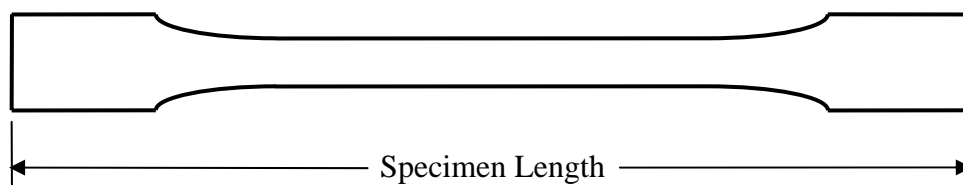
**Table 1** – Common Shrinkage Values For Generic Thermoplastics

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<sup>1</sup> See <http://www.gepolymerland.com/research/tech/tip97dec.html>

MATERIAL	SHRINKAGE (per ASTM D955)
	(in./in.)
ABS- High Impact	.005 - .007
ABS- Medium Impact	.005 - .008
ABS-High Heat	.004 - .006
ACETAL	.020 - .035
ACRYLIC- General Purpose	.002 - .009
ACRYLIC- High Flow	.002 - .007
ACRYLIC- High Heat	.003 - .010
ACRYLIC- Impact	.004 - .008
NYLON- 6,6	.010 - .025
NYLON- 6	.007 - .015
NYLON- Glass Reinforced	.005 - .010
POLYCARBONATE	.005 - .007
POLYESTER .025 - .050 thick	.006 - .0012
POLYESTER .050 - .100 thick	.012 - .017
POLYESTER .100 - .180 thick	.016 - .022
POLYETHERIMIDE	.005 - .007
POLYETHYLENE- LDPE	.015 - .035
POLYETHYLENE- HDPE	.015 - .030
POLYPROPYLENE	.010 - .030
PPO®/HIPS (NORYL®)	.005 - .007
POLYSTYRENE- Crystal	.002 - .008
POLYSTYRENE- Impact	.003 - .006
POLYURETHANE	.010 - .020
PVC-RIGID	.002 - .004
PVC-FLEXIBLE	.015 - .030
SAN	.002 - .006

To accurately predict shrinkage in injection molded parts, accurate shrinkage rates for the plastic your AML team will be using is required. This lab exercise allows you to experimentally determine shrinkage rates for five common polymers using a statistically significant number of test samples. Specifically, the length of injection molded tensile test specimens (ASTM D638), as shown in Figure 1, will be measured. The five polymers and the order in which they will be tested are listed in Table 2.



**Figure 1** – ASTM D638 tensile test specimen being used to measure polymer shrinkage values.

**Table 2** – Polymers available in AML to be tested.

<b>Polymer</b>	<b>Relative Melting Temperature</b>
Polypropylene	Low
Polyethylene	Low
ABS	Medium
Acrylic	Medium-High
Polycarbonate	High

Specific tasks for this lab exercise are as follows:

1. Measure the length dimension  $L$  in the AML tensile test specimen injection mold. Note that this dimension will change as the mold is heated up due to the circulating water. The actual mold cavity length  $L_c$  during injection molding will be

$$L_c = L \left[ 1 + \alpha (T_{mold} - T_{ambient}) \right] \quad (4)$$

where:  $\alpha$  = coefficient of thermal expansion for aluminum mold =  $12.8 \times 10^{-6}$  1/°F

$T_{mold}$  = mold temperature in °F (probably the heating water temperature)

$T_{ambient}$  = ambient temperature of the AML in °F.

2. For a particular polymer, injection mold 30 standard tensile test specimens using the AML mold. Measure the lengths of all 30 specimens after they cool to room temperature using a Vernier Caliper, and calculate the average length  $L_{ave}$  and standard deviation  $\sigma_L$ .
3. Calculate the shrinkage rate for the polymer S using the following equation:

$$S = \frac{L_c - L_{ave}}{L_c} \quad (5)$$

4. Repeat Steps 1-3 for each polymer.
5. As a group, submit a 2-3 page report that describes the results of the shrinkage rate measurements, discusses the variability in the data as measured in Step 2, and includes all of the raw measurement data.