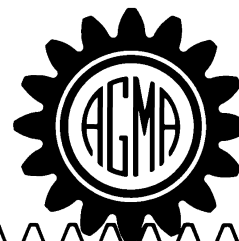


Material Integrity in Molded Plastic Gears and its Dependence on Molding Practices

by: T. Vale, ABA-PGT, Inc.

American Gear Manufacturers Association



TECHNICAL PAPER

Material Integrity in Molded Plastic Gears and its Dependence on Molding Practices

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

The quality of molded plastic gears is typically judged by dimensional feature measurements only. This practice overlooks potential deficiencies in the plastic injection molding process and its effect on the integrity of the plastic material. These deeper issues are often not given proper consideration usually until a related gear failure demands its study and evaluation. This paper identifies some of these oversights in the molding process, the resultant effect on the plastic material and discusses their likely effect on short and long term gear performance.

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It is standard practice in the gear industry to define the quality of a gear based on physical measurement of size and form. This is never more evident than in the AGMA gear quality ratings where measured values of total composite error (TCE) and tooth to tooth error (TTE) are used to neatly categorize and rate the quality of a gear. Beyond that, a great deal of effort might also be placed on using more advanced metrology equipment to gather more and more information about the size and form of the gear. This could include using elemental inspection to get detailed information about the involute and lead of the gear, using optical or a coordinate measuring machine to define the form of the inner diameter (ID), the flatness of the part, the profile of other features on the gear or using a profilometer or other technique to quantify the surface finish of the gear teeth. This is all good information to have about your gear. In machined metal or plastic gears, if you have started with a quality piece of raw material, you can be confident that if physical measurements are repeatable and within specification, your gear supplier has done a fine job of supplying you a quality gear. With molded plastic gears, this practice of relying on physical measurements as proof of quality overlooks potential deficiencies in the injection molding process and the effect it may have on the integrity of the plastic material.

The scope of this paper is to spotlight these molding deficiencies and to discuss the hidden effects they can have on the end properties of your plastic gear. There is a lot of published data available on the physical properties of every type and grade of plastic imaginable. What is less available and often disregarded by both end users and molders of plastic gears is information on just how these published properties are affected by processing conditions during injection molding. When published data is compiled there is a certain amount of care that goes into assuring that test specimens have been molded using optimum molding conditions which will in turn yield the best physical properties. Optimum properties of the plastic material cannot be achieved with-

out optimum processing conditions. Proper part design plays a major role in getting the most out of your plastic material, but with all things equal, if proper care is not taken during molding, all of the up front analysis done by a gear designer can quickly become meaningless. In addition to reducing physical properties, poor molding will also create the conditions for failure modes that could not be predicted or accounted for by even the most prudent of designers.

It is also important to note here that there is no way around the fact that a high quality molded plastic gear starts with the design and construction of a high quality plastic gear mold. This mold shall always have proper cooling channels, venting, properly sized gates and runners, sufficient coring, sufficient ejection capabilities, quality mold surface finish, precision fits and tolerances, concentricity between mold components and proper steel selection. This paper will not focus on why those things are important or how they are achieved. Instead it will be assumed that a very sound mold with all of these considerations has been produced and is being used. This paper will describe the things that can go wrong regardless of the mold and part design if the gear molder is not disciplined and committed to molding a high quality gear from the inside out.

Crystallinity and shrinkage

When studying the relationship between processing and end properties of a molded gear, the two most basic fundamentals that need to be understood are that of crystallinity and shrinkage. For purposes of this paper, it is important to have a basic understanding of these for three reasons: 1) The amount of crystallinity in a semi-crystalline polymer has significant impact on the end properties of the plastic. 2) Improperly predicted shrinkage is often a key driver behind why a molder would choose to violate general good molding practice in an effort to get a part that meets the physical size requirements specified on the part drawing. 3) Shrinkage and crystal-

linity are both highly dependent on the process conditions ultimately controlled by the mold.

Most plastics fall neatly into one of two categories: amorphous or semi-crystalline. All plastics, regardless of their level of crystallinity are comprised of many polymer chains. With an amorphous material, the full length of all the polymer chains remains in a somewhat random state before, during, and after heating the material to the required processing temperature. The difference in the polymer at low temperature vs high temperature is that at higher temperature there is more space between the polymer chains allowing them to move more freely. See Figure 1. This increased free volume and heat energy is what eventually allows the plastic to flow and be injection molded. With a semi-crystalline material, you will find these same amorphous (random) bunches of polymer chains. However, in addition you will also find areas of tightly packed, regularly shaped crystalline structures called spherulites. These spherulites are made up of many sections of polymer chains called lamellae that have folded up upon themselves and are held tightly together due to intermolecular forces acting between the folded sections of polymer chain. See Figure 1.

This tight packing and intermolecular forces are what gives the semi-crystalline plastic (such as acetal or nylon) the properties that are desirable for gear applications. These include friction and wear properties, chemical resistance, and strength. Heating of a semi-crystalline material through its melt temperature effectively melts any crystalline structure that may have existed in the plastic pellets before processing causing the polymer chains to go back to a widely spaced random state very similar to an amorphous material at its processing temperature. It is upon cooling of the material back through its crystallization temperature that crystalline structures are formed once again. How quickly the polymer is taken from its melt temperature down through this crystallization temperature will determine both size and quantity of crystalline structures formed. So the resultant crystallinity of any molded gear is very much determined by the gear mold.

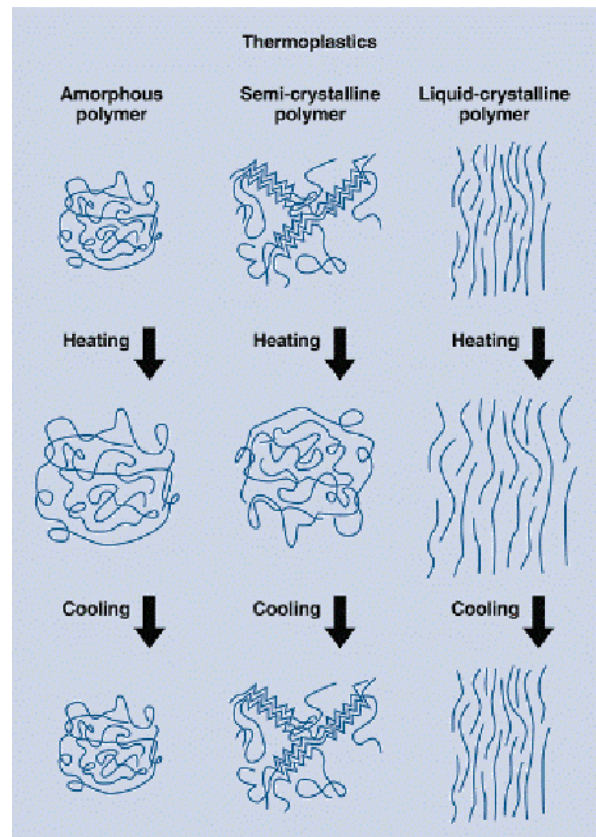


Figure 1. Amorphous vs semi-crystalline polymer chains
(courtesy DSM)

Mold shrinkage is the difference in size between a mold cavity and the molded product that is produced in that cavity. Most simply, shrinkage is a product of thermal expansion. Like most all materials, plastics will expand when heated and contract when cooled. Given the relatively high CTE of plastics (typically 5 – 25 x that of steel) and the high processing temperatures used during injection molding (typically 350°F – 700 °F above room temperature), properly predicting and managing this heating and cooling of the plastic during molding is critical in getting a high quality part. Plastic (with no fillers) shrinkages range from approximately 0.4% to 4% of the cavity dimensions depending on processing conditions and part geometry.

In addition to the shrinkage caused by thermal expansion, semi-crystalline materials exhibit additional shrinkage as the dense crystalline structures