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Designing a plastic part is more than skin deep

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While design involves the traditional definition of form, function and cosmetic appearance, it embodies more than just how the part looks: Design involves many steps, along with cross-functional collaboration, to be successful. It includes the resin that will be used, as well as the additives to increase longevity and safety, and reinforcements to enhance mechanical properties. Design comprises the geometric features that provide support, cover, feel and shield. It is intimately involved in the ability to manufacture the part and assemble it with other parts to create an assembly or product, referred to as design for manufacturing and assembly (DFMA) or design for processing (DFP). How the part functions, behaves, lives and interacts with its surroundings is directly related to design.

Not being the least important, design plays an exceedingly important role on cost. Design establishes the complexity of the manufacturing process, the elaborateness of shape and size, and multiplicity of the materials to be used, which all obviously heavily influence cost. At the same time, design is highly associated with the inherent and perceived value of the part. Design is so intertwined with the many aspects of successful part development that without a keen focus on it and the understanding of its importance at every step, the final part is likely to fail at some point along the development process, during manufacturing or while in the field. Early and repeated attention to the details of all aspects of part design can play a crucial role in manufacturing success, true and perceived quality, appearance, costs, prevention of failure and part longevity.

Nearly everyone who has been involved in the product development process can attest to the fact that cost can make or break the existence of a part. It is common for a superior design to be subjected to value engineering to investigate where costs can be trimmed to create savings. Sometimes these cost savings are real, with little bearing on quality, appearance and function. At other times, these changes are made without proper knowledge of their implications. This happened several years ago on a project involving a large metal part that was being converted into a plastic. Using plastic would allow the company to design the part with a relatively complex geometry, which, in turn, would make the end-use device more efficient and quieter. It was revolutionary and was going to be a slam-dunk success. The original plastic part, which had a number of unavoidable knit lines, was to be made out of 30% glass-reinforced polyamide 6/6. The part was well designed, with most aspects of proper design addressed. Unfortunately, the decision makers determined that switching to a glass-reinforced polypropylene was going to save money. Not a difficult calculation to make and they were correct in determining that material costs would be reduced. The short-term properties and finite element analysis indicated that the part would perform satisfactorily with this new material; thus, it appeared to be a no-brainer. Fortunately, the engineers wanted to confirm the long-term performance of this new material and put into place a series of test modules to accelerate lifetime behavior of the part. During this testing, the product made of polypropylene began to fail much earlier than expected, while the polyamide 6/6 product exhibited no such behavior. To confirm the mechanism of failure and predict longevity of the part, it was requested that lifetime analysis be done.

Many people that are familiar with composite materials understand that the reduction in mechanical properties at the knitline are material dependent. Further, fiber-reinforced materials typically exhibit a larger percent reduction in properties at the knitline than neat materials. Polypropylene is notorious for poor knit-line strength. However, knitline strength is only part of the story. Plastic materials are time dependent, and multipoint data (properties over time, for example) should be considered in certain situations. To explore the long-term mechanical behavior of both reinforced materials, dynamic mechanical analysis (DMA) was run at various temperatures to predict material creep. The details of this technique are beyond the scope of this article, but it is based on the fact that polymeric materials exhibit an equivalency of temperature and time. With this method, a series of short-term mechanical tests at increasing temperatures are run and then time-temperature superposition (TTS) is employed to create a creep curve, which is then used to predict the long-term behavior [1].

First, the failure criterion was established as the equivalent yield at strain [2]. Test samples of the glass-reinforced polypropylene and nylon parts were molded with and without a knitline. The equivalent yield at strain at the maximum operating temperature was measured following ASTM D 638. Table 1 shows the equivalent strain at yield for the polypropylene sample, and Table 2 for the dry and conditioned polyamide 6/6 samples. As expected, the equivalent strain at yield is higher for the glass-reinforced dry and conditioned polyamide samples. The creep curves for both materials at the elevated service temperature, and the calculated stress level at the knitline, are presented in Figures 1 and 2. As expected, the strain is predicted to increase over time (creep). Failure is predicted to take place with the glass-reinforced polypropylene part after approximately seven weeks (1200 hours) of operation, while failure is not predicted to take place, within the timeline analyzed, for the polyamide 6/6 part. It is important to note that by simply using single point data (ASTM D 638, for example), the predicted strain would be the data point to the extreme left on each graph. More importantly, failure would not have been predicted. Without this foresight, the possible consequence of changing materials with the intent of saving some notable costs, this project would have likely ended in a disaster with significant warranty costs and a damaged reputation.

There is a natural affinity and enticement to modify the design and/or use it as a tool to reduce cost. Lean engineering has its place, and areas of savings need to be explored, or neither the part nor the company may exist for any length of time. However, the opposite is also true. Cutting costs, with no regard to understanding the consequences, can lead to the same ending. Discipline and sound judgment need to be in place to ensure good design at an acceptable cost. Most definitely, design can be used effectively to keep costs under control while creating a structurally sound and visually pleasing part—in a sense, you can "have your cake and eat it, too." It is a concept that will be stressed repeatedly in this design series, and one that Steve Jobs essentially built Apple around, and that Jony Ive perpetuates with Apple products today—simplicity.

About the author

Paul J. Gramann, PhD, PE, is President of The Madison Group, which has been providing consulting services, technical expertise and innovative technology to the plastics industry since 1993. The company is headquartered in Madison, WI.

References:
[1] Gramann, P.J., J. Cruz, and J. A. Jansen, “Lifetime Prediction of Plastic Parts - Case Studies,” SPE-ANTEC, 2012.
[2] Sepe, M., “The Materials Analyst: Part 67,” A matter of time – Part 1, *PlasticsToday*, August 2005.

Table 1. Mechanical properties of glass-reinforced polypropylene: At/away from knitline.

Sample	Stain at Yield	Stress at Yield	Modulus	% Modulus
	%	MPa	MPa	Knitline/No.
No Knitline	**2.05**	**50**	**4,826**	**24.7**
Knitline	**1.12**	**12.1**	**1,193**	

Table 2. Mechanical properties of glass-reinforced polyamide 6,6: At/away from knitline.

Condition	Sample	Stain at Yield	Stress at Yield	Modulus	% Modulus
		%	MPa	MPa	Knitline/No.
Dry	**No Knitline**	**3.25**	**90.3**	**4,771**	**67.9**
Dry	**Knitline**	**4.35**	**68.1**	**3,241**	
Conditioned	**No Knitline**	**4.33**	**75.4**	**3,289**	**69.6**
Conditioned	**Knitline**	**5.55**	**55.9**	**2,289**	

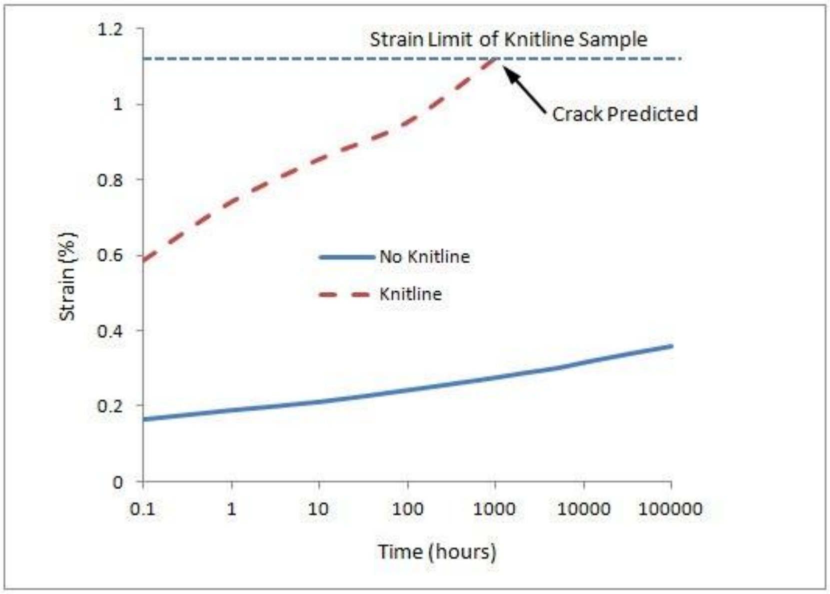

Figure 1. Predicted strain over time (creep) at 1000 psi at 165 °F (74 °C) with and without a knitline for glass-reinforced polypropylene.

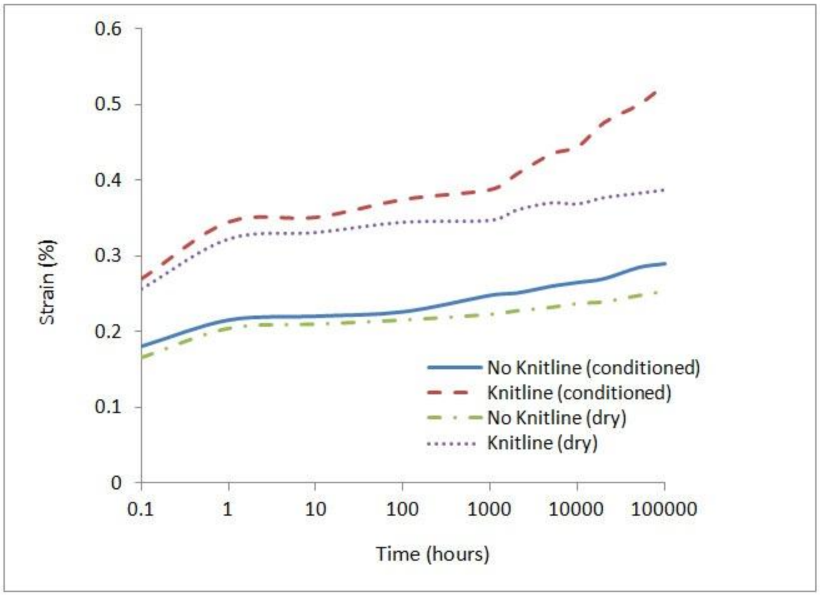

Figure 2. Predicted strain over time (creep) at 1000 psi at 165 °F (74 °C) with and without a knitline for condition and dry as-molded polyamide 6/6.