Deciding When to Go Plastic

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QUESTION

Can my metal gear(s) be replaced with plastic gears?

Expert Response Provided by Joseph L. Elmquist, R&D designer, Kleiss Gears:

As specialists in the design, manufacture, and inspection of polymer injection-molded gears, we get asked this a lot. The answer, unsurprisingly, is a definite maybe. It really depends upon the application and how the performance is evaluated. Typically, someone asking this question is looking for a cost savings, but for many applications polymers are a better material choice than metals for gearing. Depending upon the application and critical design objectives, a polymer substitution may provide a significant increase in performance benchmarks and/or a reduction in cost. Polymers exhibit fundamentally different behavior than that of metals; their mechanical properties are heavily time-and-temperature-dependent. In a dynamic application such as gearing, these dependences, if designed correctly, can contribute to polymer gears vastly outperforming metal gears in many performance benchmarks including noise, vibration and harshness (NVH), with a gear strength much higher than material predictions would indicate. As a result, we have seen applications where:

- Polymer gears out-performed metal gears in performance and cost
- Polymer gears performed comparably to metal gears, and at a cost reduction
- Polymer gears out-performed metal gears in performance, at a cost increase
- Polymer gears were not suitable
- Metal gears were not suitable

With this in mind I would like to discuss how to determine if polymer gears are good candidates for a particular system. I will summarize the performance characteristics of polymer gears and discuss general differences between polymer and metal gear design and manufacture.

The most critical consideration when deciding if polymers may be a good material choice for a gearset is environmental. If the temperature is above 150°C, the mechanical properties of even our highest-performance polymers degrade significantly, and polymer gears become unpractical. A chemical environment may drive the consideration towards, or away from, polymers as a material choice. We often see this as a driving consideration in medical applications where metals and their necessary lubricants are often unsuitable.

If the environment is one in which a polymeric material can survive, the next most critical consideration is strength. A common misconception is that plastic gears are cheaper, but weaker, versions of metal gears, and therefore accounting for the decrease in material yield strength alone will accurately represent plastic gear behavior. This is inaccurate at a fundamental material level, and it becomes rapidly apparent within a gearing application. While a metal gear under load may have line contact between gear and pinion, and a contact ratio such that only one tooth is in mesh, the involute surface of a polymer gear under load will deform under similar loading conditions, distributing the contact pressure over a larger surface, and tooth bending will initiate contact between adjacent teeth, resulting in load sharing (Fig. 1). This can result in a polymer gear having higher life expectancy than a metal equivalent in certain applications. Typically these are applications where there is high-impact loading, with a relatively low steady-state load.

As a result of the lower polymer modulus and damping properties, polymer gears almost always significantly out-perform metal gears in NVH. While there is variation in the degree to which different polymers improve in this measure, in our experience a polymer replacement in a spur gear pair typically reduces sound levels between 2-5 dB, with a reduction in frequency, no ringing, and a more uniform sound level.

Material weight can also dramatically improve transmission efficiency and response. With a lighter material, system inertia can be dramatically reduced, contributing to a more responsive and efficient system. There are many applications where overall system weight is a critical parameter, such as in the aerospace industry, and polymer gears are one potential solution.

Polymer material properties also play a role in lubrication requirements. Many polymer gears will run in some kind of lubricant; however, polymer gears have lower lubrication requirements than metal gears, reducing the complexity of, or even negating the need for, complex lubrication systems. It is often even possible to embed lubricants such as Teflon or graphite in the polymer gear material, or remove lubrication entirely.

The last property of polymers I want to discuss is cost. Obviously, this is a critical consideration in any production component. Typically at the production level, an injection-molded polymer gear costs less to produce than a metal one. The material and per-part processing costs are typically, but not always, less than the metal counterparts. There can also be significant cost advantages to injection molding, such as the ability to produce multiple parts simultaneously in multi-cavity tools. While upfront tooling costs are typically higher, over the course of a production run, a higher-performance polymer gear may cost 10-50% less than a metal one. These savings do not account for cost savings or revenue gains due to improved performance, which are also likely to be present. However, actual figures are highly project-dependent.

Due to the differences in the material properties, and manufacturing techniques of metals and polymers, different design expectations are needed. From a design perspective, the injection molding process contributes geometric flexibility at the expense of tolerance precision. With our injection-molded gears, the dimensional tolerance is on the order of < 0.025 m/m, while the repeatability is typically an order-of-magnitude better. This is an acceptable trade-off because polymers, with their lower modulus, are more forgiving of small dimensional errors than are metals. To further strengthen a polymer gear and to fully utilize its novel polymer characteristics, it is highly desirable to use a shape-optimized design. Where metal gears are traditionally defined by their machine process and tools, an injection-molded polymer gear has the advantage of being definable directly by the gear geometry. As a result of this trade-off and the fundamentally different behavior of polymeric materials, the first step in a polymer gear design is to evaluate the entire system for suitability, followed by a polymer-optimized and application-specific design, then prototyping, and finally production tooling and molding.

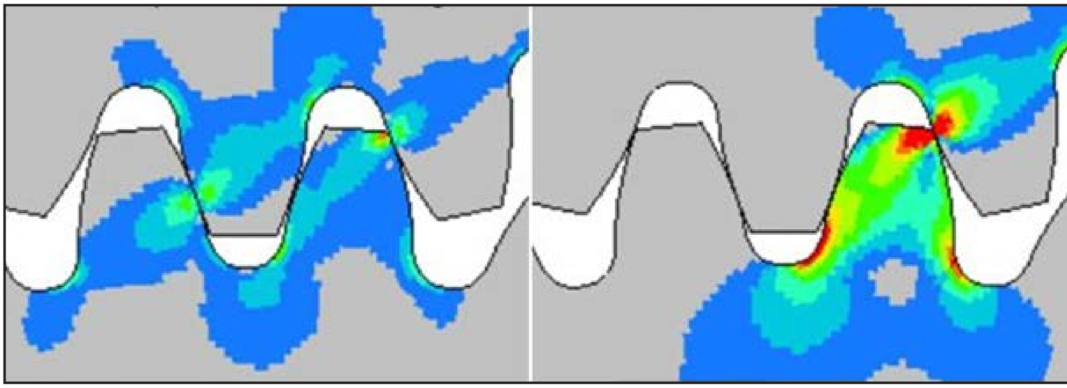

Figure 1 Finite Element simulation of a loaded polymer-polymer mesh (left) and loaded steel-steel mesh (right) showing load sharing between teeth under load. The contact ratio for the steel mesh under load is 1.2, while the polymer mesh under load has a contact ratio of 2.1 (Analysis courtesy of Vitrex USA.)

To answer the original question: if the environment does not exclude the use of polymer gears, and you are looking for an improvement over metal gears in cost, weight, NVH, and/or design simplicity, the likely answer is a resounding *Yes.*

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