ASCEND® PERFORMANCE MATERIALS

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How polyamide 66 performs against next-best resins

Polyamide 66's (PA66) unique set of properties, most notably the ability to maintain its integrity in high heat, has made it a critical material in a variety of applications. Use of PA66 has grown three to four percent annually for the past decade; that growth is projected to continue.

Because of that increase and other market factors, supply of PA66 tightened in 2017 and 2018. One major reason for this tightening was the availability of adiponitrile (ADN), a key precursor of PA66. Ascend Performance Materials and other major producers are addressing the situation by investing in ADN and PA66 polymerization capacity expansions.

As the world's largest fully integrated producer of PA66 resin, Ascend invests in capacity throughout the production chain for PA66. In 2017 and 2018, Ascend expanded production of ADN, hexamethylene diamine, PA66 resin and compounds. By 2022, Ascend will increase production to support an additional 100 kilotons of PA66. When complete, these expansions will represent the largest investment in PA66 capacity since the 1960s.

Ascend's increased efforts are designed to keep pace with market growth and ultimately relieve the supply tightness of PA66 within two years. In spite of this, some processors and manufacturers are concerned about the near-term availability and cost of PA66 for their applications, leading some to search for substitutes to a polymer ideally suited for their applications.

Material selection is predicated on performance, processability and value. Finding alternative materials is a resource-intensive process that requires a thorough review across performance and processing characteristics. The challenge is to find a material that performs well over time, can be molded efficiently and consistently, and offers value beyond the cost per kilogram.

This paper will illustrate PA66's superior performance, processability and value relative to next-best materials. None of these alternatives, however, can match the unique mix of properties that makes PA66 the ideal material for applications in many industries.

The next-best materials

No single alternative exists to cover the variety of current PA66 applications, but a handful of engineered plastics have been suggested. The most commonly cited alternatives are polyamide 6 (PA6), polybutylene terephthalate (PBT) and polyoxymethylene (POM).

Comparing these alternatives to PA66 seems straightforward: melting temperature versus melting temperature or flammability versus flammability. Figure 1 illustrates that, when compared individually, these properties, with the exception of thermal performance, seem similar and may approximate the performance of PA66 in any given application.

Some in the industry even suggest designing around the substitute material's shortcomings, as though that would be a trivial exercise. Take high-heat automotive applications, for example. PA66 has become a material of choice because as automakers create more efficient vehicles, the thermal load under the hood has increased dramatically. Able to withstand instantaneous and prolonged exposure to elevated temperatures, 30 percent glass-filled PA66 is used to create charge air coolers, ducts and cylinder head covers – all parts that need to operate in extreme conditions. Notably, PA66 performs reliably during the life of the vehicle.

The next-best materials in these applications are PA6 and PBT, which have a nearly 50°C heat-deflection temperature deficit compared to PA66. Switching to either of these materials would require automakers to design entirely new systems to reduce the heat under the hood.

"Some suppliers of thermoplastics are seeing an opportunity to move into applications specifically designed for PA66 with alternatives," said Steve Manning, Ascend's senior director of nylon product technology. "Unfortunately, they're presenting some of these alternatives as drop-in replacements, and that is simply not the case."

Part performance seldom relies on a single property. Cable tie molders, for example, are concerned not only with the impact resistance or weathering of the finished cable tie but also with how well the raw material behaves during molding and how quickly they can produce cable ties without defect. Replacing one material with another based on a single property is often not advisable.

So how does PA66's unique mix of properties make it the preferred material for so many diverse applications?

Figure 1. Table of Properties of PA66, PA6, PBT and POM

	Units	PA66	PA6	PBT	POM
General Properties		**30% GF**			
Density	g/cm^3	1.37	1.36	1.52	1.58
Crystallization Rate @ Tmax	$T_{1/2}$ sec^{-1}	1.64	0.14	0.05	0.02
Relative Crystallization Rate	vs POM	82x	7x	2.5x	1x
Moisture Absorption (23 °C; 24 hr)	%	0.9	1.9	0.15	0.2
Mechanical Properties		**30% GF**			
Flexural Modulus (23 °C)	MPa	9600	9500	9000	8600
Tensile Stress (Yield, 23 °C)	MPa	195	180	130	106
Tensile Strain (23 °C at Break)	%	3	3.5	2.5	2
Impact Strength (23 °C; Notched Izod)	kJ/m^2	12	12	10	6.4
Thermal Properties		**30% GF**			
T_g	°C	10–50	10–50	45	–65
T_m	°C	260	220	225	170
T_c	°C	220	172	188	150
HDT (1.8 MPa, Unannealed)	°C	250	200	205	160
Electrical Properties		**Neat**			
Flammability	UL 94	V2	HB	HB	–
Dielectric Strength (1.00 mm)	kV/mm	26	17	22	–
CTI (3.00 mm)	V	600	600	<599	–
Chemical Resistance		**Neat and 30% GF**			
H_2O	E = Excellent, G = Good, F = Fair, P = Poor	E	F	F	F
Weak Acids		G	G	G	P
Weak Alkalis		E	E	P	P
Strong Alkalis		F	F	P	P
Organic Solvents		E	E	E	E
Alcohols		G	G	G	F
Hydrocarbons		G	G	P	P
Fuels		G	G	G	G
Gamma Radiation		F	F	G	P
UV Radiation		F	F	F	P
Processing Characteristics		**Neat and 30% GF**			
Mold Shrinkage					
Across Flow: 23 °C, 2.00 mm	%	1.80/0.90	1.80/0.90	1.70/1.00	1.70/0.80
Flow: 23 °C, 2.00 mm	%	1.70/0.40	1.70/0.30	1.60/0.30	1.60/0.40
Viscosity Number	cm^3/g	155	249	160	–
Molecular Weight	g/mol	226.32	113.16	220.23	30.3

Source: industry literature

A unique mix of properties

Chosen primarily for its ability to maintain integrity after short-term and prolonged exposure to elevated temperatures and stress, PA66 has become the preferred material in demanding applications. Its strength, density, heat and chemical resistance, electrical properties and processability combine to make it the most appropriate material across applications as diverse as cable ties and electrical connectors.

This diversity results from the unique mix of properties that PA66 offers. PA66 offers the best balance of performance and overall system cost. Below are some of the applications where PA66 is ideally suited and why an alternative material will likely fail to meet the same performance requirements.

Automotive: Lighter, stronger, hotter

The automotive industry, driven by a number of trends, has become a prime user of PA66 engineering plastics.

The move toward greater fuel efficiency without sacrificing performance has led to greater adoption of turbocharged internal combustion engines, vehicle lightweighting, and hybrid and electric vehicle drivetrains.

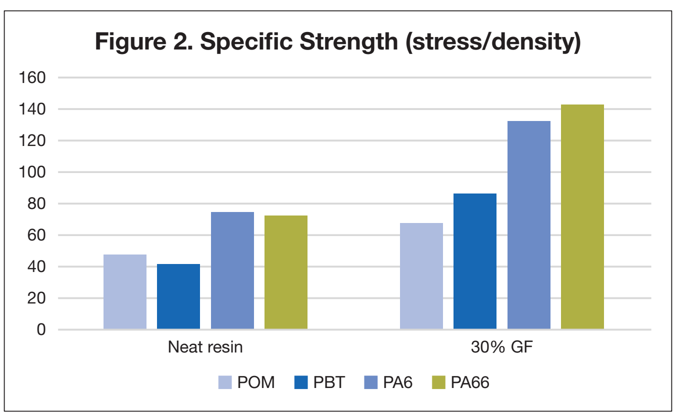
Engine downsizing and turbocharging have increased temperatures under the hood. Metal manages thermal load efficiently, but its heavy weight is a drag on fuel efficiency.

PA66 has become automakers' material of choice because of how well it handles an increased thermal load while reducing vehicle weight. The next-best alternatives would require vehicle designers to sacrifice thermal performance and specific strength. Choosing 30 percent glass-filled PA6, for example, would require approximately 10 percent more material to meet the strength requirements met by PA66, yet still fall short of the thermal requirements.

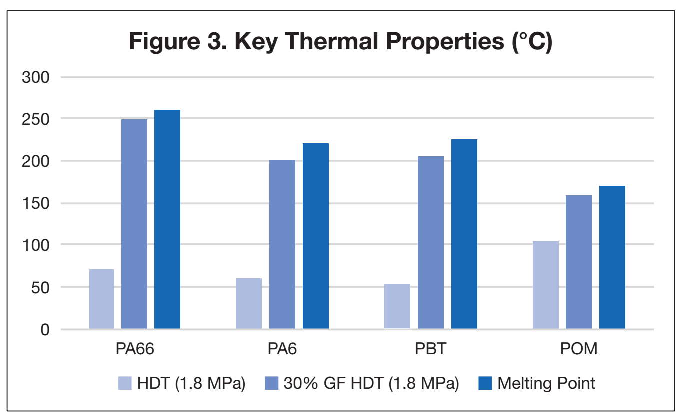
Even in lower-temperature applications, PA6 does not meet the strength of PA66 kilo for kilo. A 10 percent increase in material to meet strength requirements not only reduces lightweighting gains, but also increases part size in an area where space is at a premium.

PBT, which has thermal performance similar to PA6, fares even worse in the strength comparison. With a specific strength only 60 percent of that of PA66, 67 percent more material would need to be used for a part made of PBT to match the PA66 part's strength. And the material still would not meet the necessary thermal load. (See Figure 3.)

"In automotive applications, polyamide 66 is primarily considered for its thermal properties, but its strength and weight are critically important as well," said Vikram Gopal, senior vice president of technology at Ascend. "This is the reason we are seeing more and more application areas in vehicles, not just under the hood."



Matching PA66's strength performance with any of the next-best materials would require more of that material and therefore reduce any possible weight savings.



PA66 outperforms all the next-best materials in terms of temperature resistance.

E&E: Resistance is crucial

For electrical and electronic applications, PA66's unique combination of properties give it a distinct advantage. Electrical current produces heat, and the connectors, wires and other infrastructure used to direct the flow of electricity must withstand persistent exposure to elevated temperatures. Furthermore, given the potential hazards should electrical systems fail, how a material behaves during a failure is vitally important.

A number of international standards ensure that materials used in electrical equipment meet critical safety thresholds. A material's classification within these standards dictates its suitability.

For example, the United States Council for Automotive Research (USCAR) classifies electrical system components based on a material's ability to withstand ambient temperatures. PBT's USCAR temperature classification of T2 to T3 means it can withstand ambient temperatures up to 125°C, rendering it suitable only for use in the passenger compartment. PA66's classification of T5 shows it can withstand ambient operating temperatures of 175°C, making it suitable for any automotive application, including under-the-hood connectors.

Another important standard is UL 94, which rates the flammability of plastic used to make electrical parts inside devices and appliances. PA66 has an inherent UL 94 rating of V2, meaning that in the event of critical failure, the material is less likely to produce a flame. The proposed next-best materials carry a rating of HB, which means they are more flammable. Flame retardant additives may boost the performance of those polymers, but they also will boost the cost.

	Units	PA66	PA6	PBT	POM
General Properties					
Flammability	UL 94	V2	HB	HB	—
Dielectric Strength (1.00 mm)	kV/mm	26	17	22	—
CTI (3.00 mm)	V	600	600	<599	—
USCAR classification		T5	T3	T3	T2

Finally, dielectric strength measures the voltage a material can withstand before breaking down. As with thermal resistance, PA66 outperforms the next-best materials handily.

As a material for electrical components, PA66 possesses properties conducive to demanding applications. PA66 is inherently more flame retardant, a better insulator at higher voltages and better at withstanding high ambient operating temperatures.

"The energy trends are pointing toward a more electrified future, from high-voltage hybrid and electric vehicles to always-on smart devices," said Dharm Vahalia, director of engineering plastics at Ascend. "PA66's role in ensuring the safe and reliable transition toward electrification cannot be overstated. None of the next-best alternatives can perform the way PA66 does in electrical applications."

Processability

Of course, none of these properties matter if a material is difficult to work with. A molder's ability to make a part is contingent on processing polymer into that part reliably, consistently and economically.

What is often missing from the discussion about raw material costs is how that material behaves during processing.

None of the proposed alternatives to PA66 match its processability. With a low viscosity, higher crystallization rate and faster cooling, PA66 outperforms the next-best materials. That performance translates into faster cycle times, allowing molders to produce parts more quickly at a higher quality.

	Units	PA66	PA6	PBT	POM
Processing Characteristics					
Spiral Flow	cm	76.7–101.4	39.1–106.9	17.0–35.0	29.9–35.0
Crystallization Rate @ T_{max}	$T_{1/2}$ sec^{-1}	1.64	0.14	0.05	0.02
Relative Crystallization Rate	vs POM	82x	7x	2.5x	1x

The spiral flow test measures the flow of a molten material under a consistent force of 6.9 MPa through a spiral mold. The farther the material travels, the better that material is likely to perform when filling a part mold.

PA66 outperforms PBT and POM by a factor of three, and performs more consistently than PA6. In processing terms, this means that PA66 can fill a mold faster, more completely and more reliably than any of the alternatives.

Furthermore, PA6 is plagued by other factors in processing. During the production of PA6 from caprolactam, achieving 100 percent conversion is extremely difficult. The residual caprolactam adheres to the mold and causes deformities in the part. Addressing the issue of caprolactam residue reduces cycle time, thereby decreasing production.

Filling a mold quickly and consistently is the first step in reducing cycle times. The next step is crystallization and cooling of the material.

PA66 crystalizes 12 times faster than PA6, nearly 33 times faster than PBT and 82 times faster than POM. Rapid crystallization means that a part hardens faster and can be removed from its mold sooner.

Figure 4. Crystallization Rate

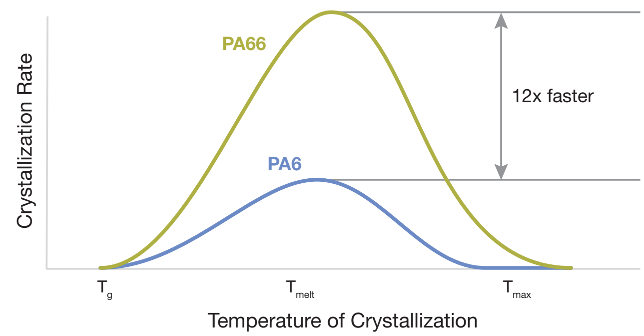
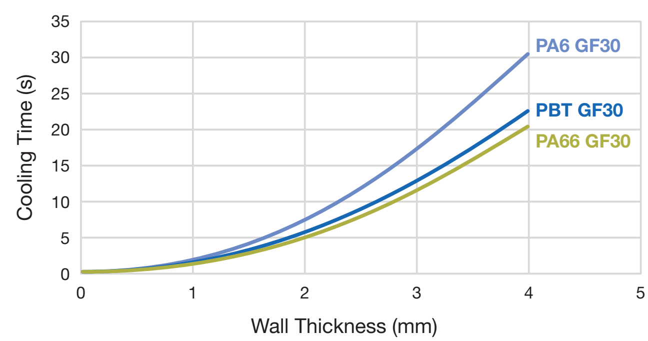


Figure 5. Cooling Time



Figures 4 and 5: PA66's rapid crystallization rate and shorter cooling time mean that more parts can be produced in a given timeframe than any of the next-best alternatives.

By filling a mold and crystalizing quickly, PA66 processes faster than any of the next-best materials. An analysis in *Plastics Technology* concluded that every second shaved off cycle time results in \$20,000 to \$50,000 in annual savings.

Value

Material selection is not predicated on performance and processability alone. Price is important. However, as illustrated with performance and processability, a material's cost should not be considered in isolation.

A tight supply of the raw materials for PA66 led to price increases in 2018, which in turn led to the misperception that PA66 had become an expensive polymer. But when considering the price of PA66 against its performance and processing benefits, PA66 remains the best value.

Take PBT for example. Parts made with PA66 are typically designed to meet set strength requirements. As mentioned previously, PBT's specific strength is 60 percent that of PA66, meaning every kilogram of PA66 must be replaced with 1.67 kilogram of PBT. Not only would the additional material cost more, but it would also require investing in system redesign and retooling.

The same story plays out with POM and PA6. Neither of those materials match PA66 in terms of performance or processability. Each performance trade-off must be met with an increase in material or an additive that increases the material's cost. Any processing trade-off increases cycle time and necessitates retooling, thus increasing the actual cost of the material.

Just as isolating a specific performance characteristic fails to provide a full picture of PA66's benefits over the next-best materials, so too does a pure cost-per-kilogram comparison. Again, replacing PA66 with a next-best material often requires costly changes, making the alternatives far less economical.

Never settle for less

PA66's superior thermal, strength, electrical and processing properties have made it a sought-after polymer. Its popularity coupled with market forces led to supply constraints in 2017 and 2018. However, with producers investing in capacity expansions for PA66 and key raw materials, those constraints are projected to be relieved in the near future.

Ascend and other producers continue to invest in research and development of new grades of PA66 – building on an already indispensable polymer's capabilities. New higher heat, high flow and flame retardant grades are further increasing PA66's performance, processability and value.

Of course, the push toward alternatives will persist beyond any capacity expansion. Producers of those alternatives have a financial stake in the success of their material, as do producers of PA66.

But isolating and comparing a single property between two or more materials provides an incomplete evaluation when choosing one material over another. The interplay of properties in PA66's unique mix is central to its versatile performance, and that is hard to beat.

About Ascend

Ascend Performance Materials is the world's largest fully integrated producer of nylon 6,6 resin. We manufacture and reliably supply world-class plastics, fibers and chemicals that are used in thousands of everyday applications such as car parts, electronics and cable ties.

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