NANOMETAL-POLYMER HYBRID

Nanocrystalline metal/polymer hybrid technology has been developed to build strong yet extremely lightweight components.

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MetaFuse nanocrystalline metal/polymer hybrid technology is based on a proprietary process in which an ultra high-strength thin metal layer is precisely applied to molded engineering polymers to create lightweight components in complex shapes with the stiffness of magnesium or aluminum, and higher strength. The metal layer in this hybrid system is unique in that it is based on a nanocrystalline microstructure in the metal, which creates high strength that cannot be matched in other traditional metal deposition processes. Nickel and nickel/iron alloys are available now, and several other metals and alloys are under development. An illustration of this hybrid system is shown in Figure 1. Strength and modulus of engineering polymers vs. metals are shown in Fig. 2.

This article explores the metal-over-plastic technology that enables a step change in performance.

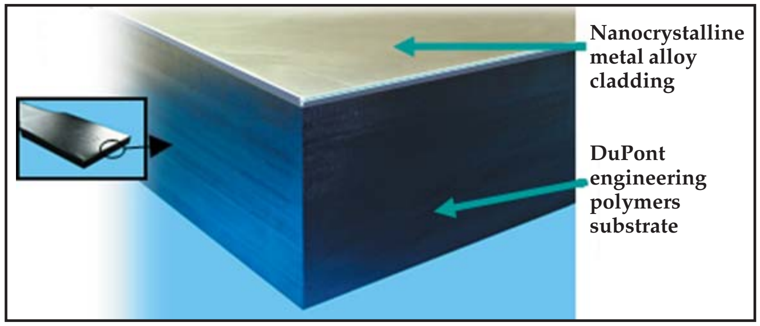

Fig. 1 — This illustration of a hybrid system shows the nanometal coating over the polymer substrate.

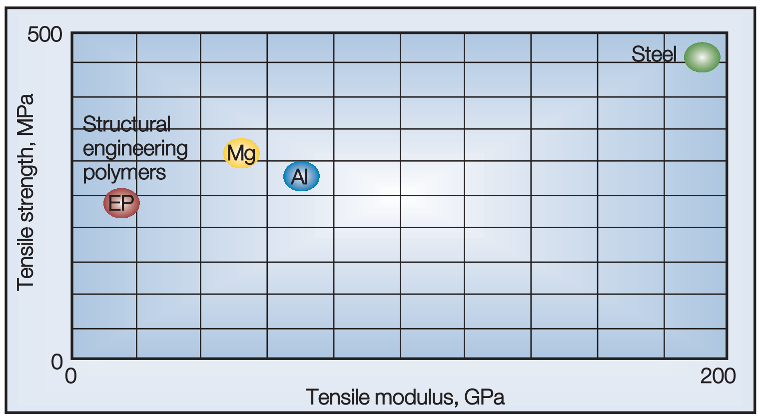

Fig. 2 — Comparison of strength and stiffness of engineering polymers and some structural metal alloys.

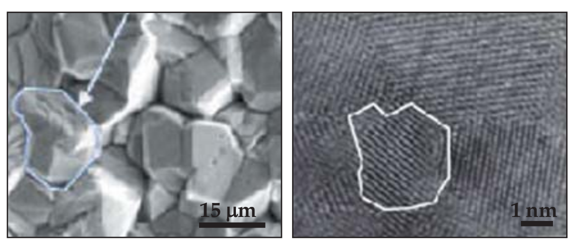

Fig. 3 — These photomicrographs show the differences in grain structures between nanocrystalline metal to conventional metal. a) shows polycrystalline material with larger grain sizes, and b) shows the nanocrystalline material. Courtesy Integran Technologies Inc.

Nanocrystalline metals

The metal layers in the nanocrystalline metal/polymer hybrids have ultra high strength, and are based on a proprietary process that provides the ability to engineer these metallic alloys by controlling their microstructure during material processing. The breakthrough enabled by this process is the ability to form fully dense nanocrystalline materials in a cost-effective process. Typically, metals possess polycrystalline microstructures, which are composed of groups of individual small crystals known as grains. Various metals exist that have identical chemical compositions but widely varying physical properties. These differences are brought about because of changes in the microstructure. Grain size is one of the factors that influences the properties of a material. The empirical Hall-Petch relationship describes the variation of the yield strength of a material with its grain size:

$$\sigma_y = A + \frac{B}{\sqrt{d}}$$

Where σ_y is the yield strength, A and B are material constants, and d is the average grain size.

This equation shows that smaller grain sizes increase the yield strength. Other properties such as tensile strength, hardness, wear resistance, and coefficient of friction are also enhanced by reducing grain size.

The new technology provides a means to produce a finely grained material. The highly optimized process reduces grain size from the micrometer scale to the nanometer scale, a factor of 1000. The photomicrographs in Fig. 3 show the differences in grain structures comparing

Property comparison of conventional nickel vs. nano-nickel

Property	Conventional nickel, 20 μm	Nano-nickel, 100 nm	Nano-nickel, 10 nm
Yield strength, MPa (ksi)	103 (15)	670 (97)	~900 (130)
Ultimate tensile strength, MPa (ksi)	406 (59)	850 (123)	~1400 (200)
Vickers hardness, kg/mm^2	140	320	450

nanocrystalline metal to conventional metal, while the table lists some of the properties of nanocrystalline nickel versus conventional nickel.

The nanocrystalline metal has an average grain size of about 20 nm, which is about 1000 times smaller than conventional metals, and is two to three times stronger than typical steels and decorative nickel-chrome. The properties exhibited by these nanocrystalline metal alloys are not only higher strength than conventional metals, but also they have properties that are comparable to those of other high-strength metals. Figure 4 shows a comparison of nanometal alloys to high-strength metals, as well as to die cast aluminum and magnesium.

The ability to deposit nanometal onto the surface of plastic parts allows the formation of this metal into complex shapes, which is very difficult to do with traditional high-strength metals. Since the nanocrystalline metal alloys have significantly higher strength than conventional metals, relatively thin layers can be applied to the surface of plastic materials to create hybrid constructions with high structural properties, unlike other metal deposition techniques, such as conventional electroplating and vapor deposition.

Mechanical properties

The MetaFuse technology enables applying nanocrystalline metal onto selected areas of a molded polymer part to increase stiffness and improve other properties. A very unique aspect of this system is that it places the metal in the optimum location to increase stiffness. Many metal and plastic parts are subjected to loads that result in bending stresses. For bending loads, the placement of the nanometal coating is most beneficial at the outermost edges of the part, furthest from the neutral axis. This is where the maximum tensile and compressive stresses are experienced, since the stresses are directly proportional to distance from the neutral axis.

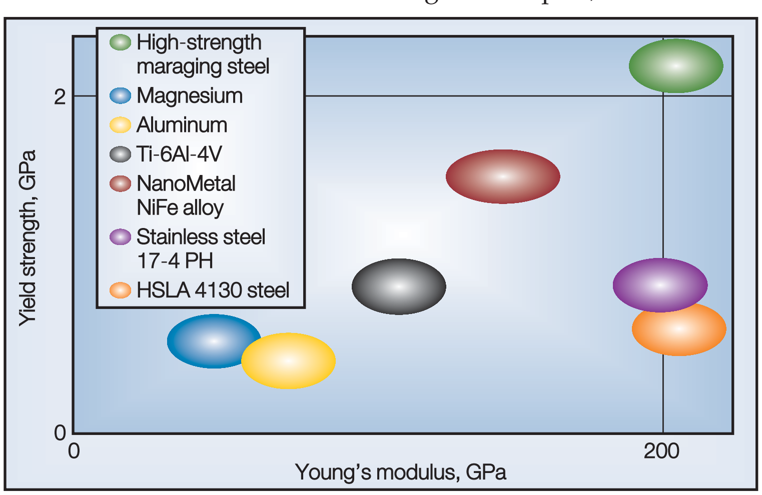

Fig. 4 — Nanometal alloys are compared to high-strength metals, as well as to die cast aluminum and magnesium.

The strong and resilient nanometals are well placed to support the load. The bending stiffness of the part increases as well, because it is a product of the modulus and moment of inertia; the inertia of the coating is increased exponentially by moving it away from the neutral axis.

Torsional stiffness and strength are also improved by moving the coating radially outwards to increase the polar moment of inertia. The outer sections experience the largest torque, and this is where the superior strength of nanometal is most beneficial.

Property testing has been completed with a number of different engineering polymer substrates to characterize properties of the MetaFuse hybrid system. The magnitude of property improvement depends on the substrate plastic, and the placement and thickness of the nanometal coating.

Typical improvement in physical properties is illustrated here based on testing of 25% glass-reinforced Zytel PA66 polymer injection molded into ISO tensile bars, and then clad with 100 microns of a nickel/iron nanocrystalline metal alloy that encapsulates the bar. Figure 5 shows a comparison of room temperature properties for the nanometal/plastic hybrid versus plastic alone in three properties: Bending stiffness as measured by flexural modulus, tensile strength, and impact strength as measured by multi-axial impact.

As shown in the data, typical increases in flexural modulus and impact strength of two to four times that of the plastic alone can be achieved. These properties are very dependent on the geometry of the sample, metal thickness, and substrate plastic material. Tensile strength is directly proportional to the metal thickness.

Testing has also shown that nanometal/plastic hybrids are able to maintain excellent structural properties in temperature ranges where polymers alone exhibit significant loss in properties. Dynamic mechanical analysis (DMA) compares plastic properties versus the nanometal/plastic hybrid. DMA is a technique in which the sample is deformed under load over a wide range of temperature conditions. From this the stiffness of the sample can be determined, and a sample modulus can be calculated.

DMA analsyis shows that plastic/metal samples retain 70% to 80% of initial modulus even when the temperature exceeds the glass transition temperature of the polymer. These data suggest that the hybrids may enable polymers in structural applications at elevated temperatures, and could extend the working temperature range of polymer parts by 50 to 75°C (90 to 135°F). However, note that results will depend on the properties of the plastic substrate.

In many practical applications, the nanometal

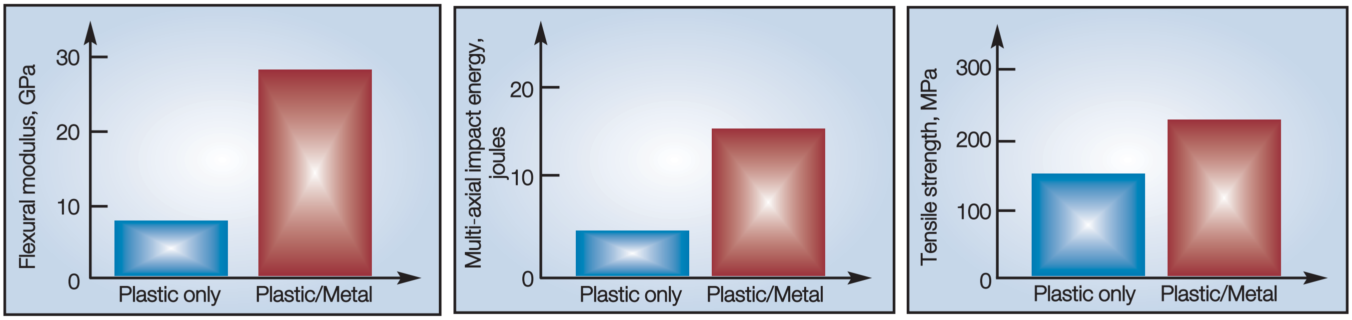

Fig. 5 — Room temperature properties for the nanometal/plastic hybrid are compared to plastic alone in three properties: Bending stiffness as measured by flexural modulus, tensile strength, and impact strength as measured by multi-axial impact.

cladding may not be needed over the entire surface of the part. In these cases it is possible to apply the nanocrystalline metal cladding only onto selected areas.

Although the primary focus of this article has been related to stiffness and strength properties, the hybrids also have the capability to provide additional benefits to plastic materials, such as wear resistance, creep resistance, electrical conductivity, chemical resistance, EMI shielding, gas/fluid permeability, and UV and hygroscopic stability.

Application areas

MetaFuse has many potential applications in automotive, consumer electronics, sporting goods, and other markets. Examples include engine oil pans, cylinder head covers, water and oil pumps, gasket carriers/gasket systems, engine timing chain tensioner arms, transmission housings and components, fuel rails, automotive electrical motors, electrical housings and covers, steering column brackets and steering system components, suspension/control arms, mobile phone frames and housings, bicycle components, fishing reels, and golf club driver heads.

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MetaFuse nanocrystalline metal/polymer hybrid is a new polymer/metal hybrid technology being introduced by DuPont Engineering Polymers and its partners, Canadian-based Morph Technologies Inc., Integran Technologies Inc., and U.S.-based PowerMetal Technologies.