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GEAR MATERIALS FOR HIGH-PRODUCTION LIGHT-DUTY SERVICE

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There are many applications where gears are used which do not require high accuracy and high-load capacity. These applications must be low in cost to meet the market cost requirement of the end product. Some parts in the automobile, the home appliance, recreational vehicle, instrument, and toy industries are but a few of the wide variety of applications where high-production, light-duty gears are used.

In selecting a gear material for an application, the gear designer must determine what the actual requirements are for the gears being considered. The design requirements for a gear in a given application will be dependent upon such things as the accuracy, load, speed, noise requirements, and material. The more stringent these requirements become the more the cost of the gear will increase. For instance, a gear requiring high accuracy because of speed or noise limitations may require several process operations in the manufacture of the gear. Each operation will add to the cost.

Machined gears which are the most accurate, can be made from many materials with good strength characteristics. However, these gears are very expensive. The cost is further increased if hardening and grinding is required which could happen where noise is a critical requirement. Machined gears should, therefore, be a last choice for a high-production gear application because of high cost.

When strength and accuracy dictate a machined gear, a wide choice of materials is available. The low alloy or carbon steels are the least expensive and are easily machined. They can be broached forged or rolled. They can be case carburized if additional strength and wear resistance are required.

One of the more common methods that is used in high-volume production of medium strength gears with fair dimensional tolerance is the sintered powder metal. In this method, a fine metal powder of iron or other material is placed in a high pressure die and pressed into the desired shape and density under very high pressure. This green part has no strength as it comes from the press. It is then sintered in a furnace under a controlled atmosphere to fuse the powder together for increased strength and toughness. Usually, an additive is used in the powder, such as copper in iron, for added strength. The sintering temperature is set at the melting temperature of the copper to fuse the iron powder together for a stronger bond than would be obtained with the iron powder alone. The parts must be properly sintered to give the desired strength.

There are several materials available for sintered powder gears that give a wide range of properties. Table I is a list of some of the more commonly used gear materials although other materials are available. The cost for volume production of sintered powder metal gears is an order of magnitude less than for machined gears.

A process that has been more recently developed is the powder metal hot forming process. In this process the sintered powder metal part is heated to forging temperature and finished forged. The hot formed parts have strengths and mechanical properties approaching the ultimate mechanical properties of the wrought materials. There is a wide choice of materials available for the hot formed powder metals process. Since this is a fairly new process, there will be undoubtly improvements in the availability of materials made from this process and the cost thereof. Development is already being conducted on high-temperature materials with a cobalt alloy which shows good results.

Because there are additional processes involved, the hot formed powder metals parts are more expensive than with the sintered powder metal processes. However, either process is more economical than machined or conventionally forged parts while retaining desired mechanical properties. This should make the hot formed powder metal process attractive to high-production parts such as in the automotive industry where high strength is needed.

Accuracy of the powder metal and hot formed processes are generally in the AGMA class 8 range. Better accuracy can be obtained in special cases and where die wear is limited which would tend to increase the cost somewhat.

Another method of producing low-cost, high-volume gears is by metal stamping and cold drawing or extruding. Any of the low alloy steels and metals such as brass, bronze, copper, aluminum, and so forth, can be used for stamped and extruded gears. The high carbon and alloy steel can be stamped with special carbide inserts. The dimensional tolerance is good with AGMA class 9 available without special care. The stamped gears are made from steel stock that is first flattened and punched. The thickness of the gear is limited at different pitch. The finer pitch gears require very thin material. There is also some drawdown which reduces the face width about 20 percent.

The cost of high-production stamped and extruded gears is about an order of magnitude less than the powder metals gears. The stamped and extruded gears generally have medium strength characteristics.

The die cast process is also used to make low-cost gears. In this process the molten metal is forced under pressure into a cold or hot chamber depending on the process used. Alloys of aluminum, magnesium, and zinc are the most commonly used materials. These die cast alloys have tensile yield strengths of 20 000 to 30 000 psi. This places them between the plastic and sintered powder metal gears for strength. The dimensional tolerance is not too good because of shrinkage from the die during cooling which is not uniform and the required draft allowances for parts withdrawal. Cost for die casting is low and intricate shapes can be easily made.

Perhaps the most economical gear available for the light-load, high-volume application is the plastic or nylon gear. Table II is a list of the more common plastic materials used for molded plastic gears. The most common molded plastic gears are the acetate and nylon resins. These materials are limited in strength, temperature, and accuracy. The nylon and acetate resin have a room temperature yield strength approximately 10 000 psi that is reduced to approximtely 4000 psi at their upper temperature limit of 250° F. The nylon material is subject to considerable moisture absorption which reduces its strength and causes considerable expansion. Larger gears are made with a steel hub that has a plastic tire for better dimensional control. The plastic gears can operate for long periods in adverse environments such as dirt where other materials would tend to wear excessively. They can also operate without lubrication or can be lubricated by the process material as in the food industry. The cost of plastic gears can be as low as a few cents per gear for a simple gear on a high-volume production basis and is probably the most economical gear available.

In summary, the selection of a material for high-volume, low-cost gears is one that required careful consideration of all the requirements and the process used to manufacture the gears. The wrong choice in material selection could very well mean the difference between success and failure. Figure 1 is a summary of the cost that might be expected for different materials and processes. It can be seen from figure 1 that the cost can span nearly three order of magnitudes from the molded plastic gear to the machined gear with stamped and powder metal gears falling in between these extremes.

TABLE I. - SINTERED POWDER METAL GEAR ALLOYS

Composition				Ultimate tensile strength, psi	Apparent hardness, Rockwell	Comment
Cu 1-5	C 0.6	Fe 94		60 000	B-60	Good impact strength
Cu 7	Fe 93			32 000	B-35	Good lubricant impregnation
Cu 15	C 0.6	Fe 84		85 000	B-80	Good fatigue strength
C 0.15	Fe 98			52 000	A-60	Good impact strength
C 0.5	Fe 96			50 000	B-75	Good impact strength
Mo 2.5	C 0.3	N 1.7	Fe 95	130 000	C-35	High strength, good wear
Ni 4	Cu 1	C 0.25	Fe 94	120 000	C-40	Carburized and hardened
Sn 5	Cu 95			20 000	H-52	Bronze alloy
Sn 10	Cu 87	P 0.4		30 000	H-75	Phospherus-bronze alloy
Be 1.5	Co 0.25	Cu 98		80 000	B-85	Beryllium alloy

TABLE II. - PROPERTIES OF PLASTIC GEAR MATERIALS

Property	ASTM	Acetal	Nylon	Polyimide
Yield strength, psi	D 638	10,000	11,800	10,500
Shear strength, psi	D 732	9,510	9,600	11,900
Impact strength, (Izod)	D 256	1.4	0.9	0.9
Elongation at yield, %	D 638	15	5	6.5
Modulus of elasticity, psi	D 790	410,000	410,000	460,000
Coefficient of linear thermal expansion, in./in., $^{\circ}F$	D 696	4.5×10^{-5}	4.5×10^{-5}	2.8×10^{-5}
Water absorption, 24 hr, %	D 570	0.25	1.5	.32
Specific gravity	D 792	1.425	1.14	1.43
Temperature limit, $^{\circ}F$		250°	250°	600°

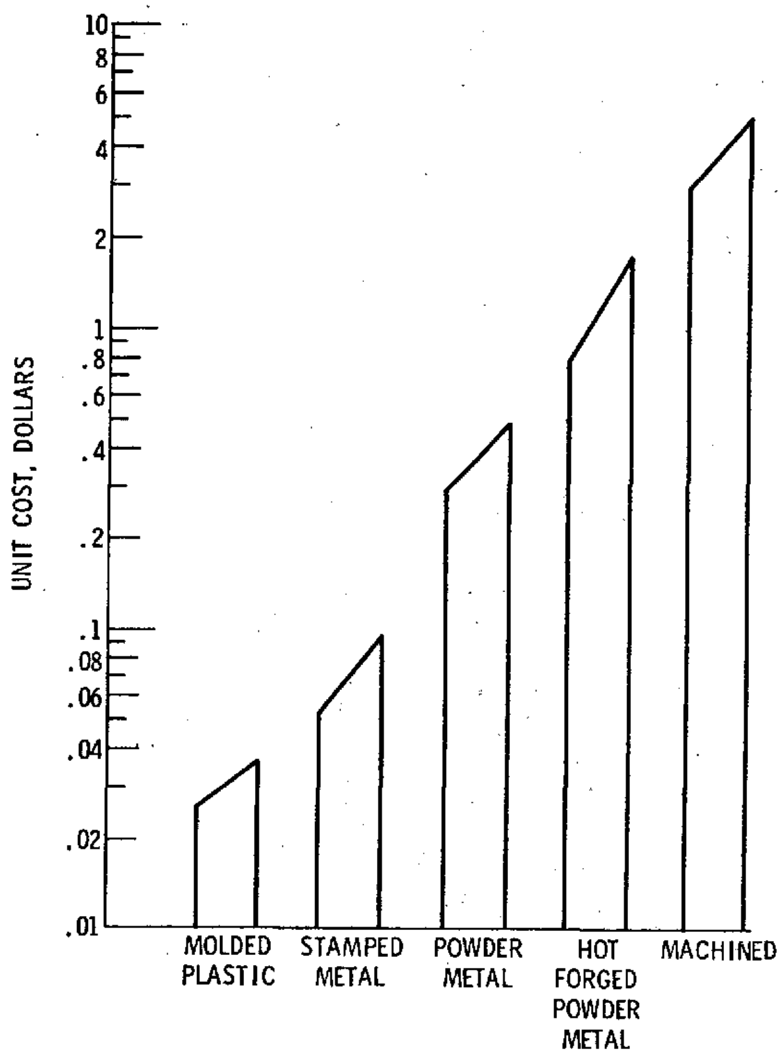

FIGURE 1. - TYPE OF GEAR