The University of Michigan
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GENERATING GEAR TEETH IN MOLDED DU PONT "ZYTEL" 101*

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INTRODUCTION

"Zytel" is the trade name for nylon resin molding material produced by the du Pont Company. It is supplied in the form of a granulated powder and lends itself to conventional methods of molding. In the molded form it is a relatively lightweight, rigid but not brittle material, having a cream to amber color.

PHYSICAL PROPERTIES

Several different types of "Zytel" are available, of which "Zytel" 101 is the most heat resistant and best suited for mechanical parts such as cams and gears. Typical physical properties of "Zytel" 101 are as follows:*

Tensile Strength, 70°F	9,300 psi
Elongation, 70°F	220%
Modulus of Elasticity, 73°F	200,000 psi
Shear Strength	8,000 psi
Impact Strength, Izod, 73°F	2.0 ft-lb/in.
Hardness, Rockwell	R108
Specific Gravity	1.14

These physical properties are somewhat affected by temperature. At higher temperatures the impact strength and percent elongation both increase, while tensile strength and modulus of elasticity decrease. The physical properties are also affected by moisture content of the molded material. Moisture

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content also affects the dimensional stability of the finished piece. When the material is conditioned after molding to have a moisture content of about 2.5 to 3% by weight, however, the material has good dimensional stability. The physical properties shown above are for this 2.5%-moisture-conditioned "Zytel" 101.

TOOTH-CUTTING METHODS

The majority of the gears made from "Zytel" 101 have molded teeth and require no machining operation. However, in those cases where the required accuracy might be beyond that readily obtainable with molded teeth, or where limited production requirements do not justify the initial mold costs, teeth can be machined into molded "Zytel" 101 blanks. Conventional tooth-cutting practices of hobbing, shaping, and shaving can all be used satisfactorily on the molded material, and cutter forms and shapes can be the same as those used for metal.

Moderately high surface speeds are desirable, but care should be taken not to allow the material to overheat. Because "Zytel" 101 is a relatively flexible material, rather fine feeds are necessary to prevent the work from deflecting excessively. Speeds and feeds comparable to those used on brass produce very good results on the finished teeth. In every case the cutters should be very sharp. Figure 1 shows various gears cut from molded blanks and molded bar stock.

ACCURACY OF TEETH

Because of the resiliency of the material, there is a tendency for the work to "spring back" somewhat after the cutter has passed. Although this

tendency is more pronounced in "Zytel" 101 than in metal, it is not enough to have harmful effects on the tooth size and shape.

Approximately one hundred 2.5-in.-pitch-diameter spur gears, one-half with 16-pitch teeth and the other one-half with 20-pitch teeth, were recently cut from molded blanks for test work. Class A hobs were used and inspection showed that none of the gears were outside AGMA Commercial 3 tolerances while many were within Precision 1 tolerances.

Figure 2 shows typical profile data obtained with a Fellows Profile Checking Machine from three teeth on each of ten 16-pitch gears selected at random. For these same gears the composite errors, measured with a Kodak Conju-Gage, were as follows:

Gear No.	Tooth-to-Tooth Composite Error, Inches	Total Composite Error, Inches
1	0.0005	0.0010
2	0.0004	0.0005
3	0.0003	0.0005
4	0.0003	0.0011
5	0.0003	0.0009
6	0.0008	0.0012
7	0.0010	0.0010
8	0.0010	0.0017
9	0.0008	0.0012
10	0.0003	0.0004

Greatest accuracy and easiest cutting were obtained when moisture-conditioned blanks were used. Any blank can be properly conditioned by immersing it for a time in boiling water, then allowing it to dry by standing exposed to the atmosphere at room temperature for approximately two weeks before machining. Boiling times recommended by the du Pont Company for 3% moisture are shown in Fig. 3. If the gears are to be cut from molded bar stock, it is best first to cut the blanks and then moisture condition in boiling water, rather than trying to condition a large piece of the bar.

One of the 16-pitch gears was never used but was inspected periodically

for several months to see if its dimensions would remain unchanged. No changes could be detected, indicating that the material is stable, even though exposed to day-to-day changes in temperature and humidity.

In addition to hobbing the teeth, several other machining operations were performed on the one hundred gears mentioned above. From this experience it is felt that the following tolerances can be quite readily obtained with molded "Zytel" 101:

Operation	Accuracy Obtainable
Turning	0.001 in.
Facing	0.001 in.
Drilling	same as with metal
Boring	0.001 in.
Reaming	0.002 in.
Broaching (spline)	0.0005 in.
Hobbing	AGMA Commercial 3
Shaving	AGMA Precision 1

The Commercial 3 and Precision 1 tolerances listed for hobbing and shaving, respectively, include 100% of the gears machined. At least 50% of the hobbed gears would be within Precision 1 tolerances, while at least this same percentage can be shaved to Precision 2 tolerances.

Inspection methods and techniques used for metal teeth can be employed. When measuring over pins, however, it is difficult to get the proper "feel," due to the softness of the molded material.

LAMINATED CONSTRUCTION

It is sometimes possible to take advantage of the tendency of the molded "Zytel" 101 to spring back after cutting, as previously mentioned. Figure

4 shows two gears and a spline made with a laminated or "sandwich" construction, with a piece of molded "Zytel" 101 between two pieces of steel. When these teeth are cut, the "Zytel" 101 profile springs back to protrude slightly beyond the steel profiles.

With this construction the gears can operate with no backlash between "Zytel" 101 profiles, while still having a small backlash between metal profiles. Furthermore, the plastic "Zytel" 101 profiles can deflect readily to compensate for expansion caused by increased operating temperatures. These features are most useful in instrument gearing, where it is often necessary to operate with zero backlash.

As previously mentioned, the "Zytel" 101 should be moisture conditioned before cutting teeth if maximum accuracy is to be obtained. However, greater protuberance of the "Zytel" 101 profile beyond the metal profiles can be obtained by cutting the teeth first and then moisture conditioning the "Zytel" 101 by immersing the entire piece in boiling water. This increase in protuberance is accompanied by a slight decrease in accuracy, however.

BURR PREVENTION AND REMOVAL

Whenever possible, teeth should be cut with a washer, or "dummy" on the side where the cutter leaves the gear. This reduces burr formation and hence facilitates burr removal. The use of such a washer for this purpose is a relatively common practice whenever small teeth are being cut from any material. Brass washers are recommended because of the similarity of cutting speeds and feeds for "Zytel" 101 and brass.

Figure 5 shows the burrs formed by cutting the teeth with and without the brass washer. The relatively light burrs formed when the washer is used can

be readily removed by the use of dry 240 grit emery paper, followed by a rotary fiber brush. However, all cutting oil should be thoroughly removed with a solvent prior to using the emery paper.

The profuse burrs formed when the washer is not used must first be hand trimmed with a sharp tool such as a razor blade. After the trimming operation, the remaining burrs can be removed with the emery paper and rotary fiber brush.

The trimming operation seems to be most easily accomplished with a slicing motion toward the center of the gear, with the cutting blade slightly inclined to the side surface of the gear. This tends to be rather tedious when the gears are produced in much quantity, however, and this operation can be eliminated by the use of the brass washer when the teeth are being cut.

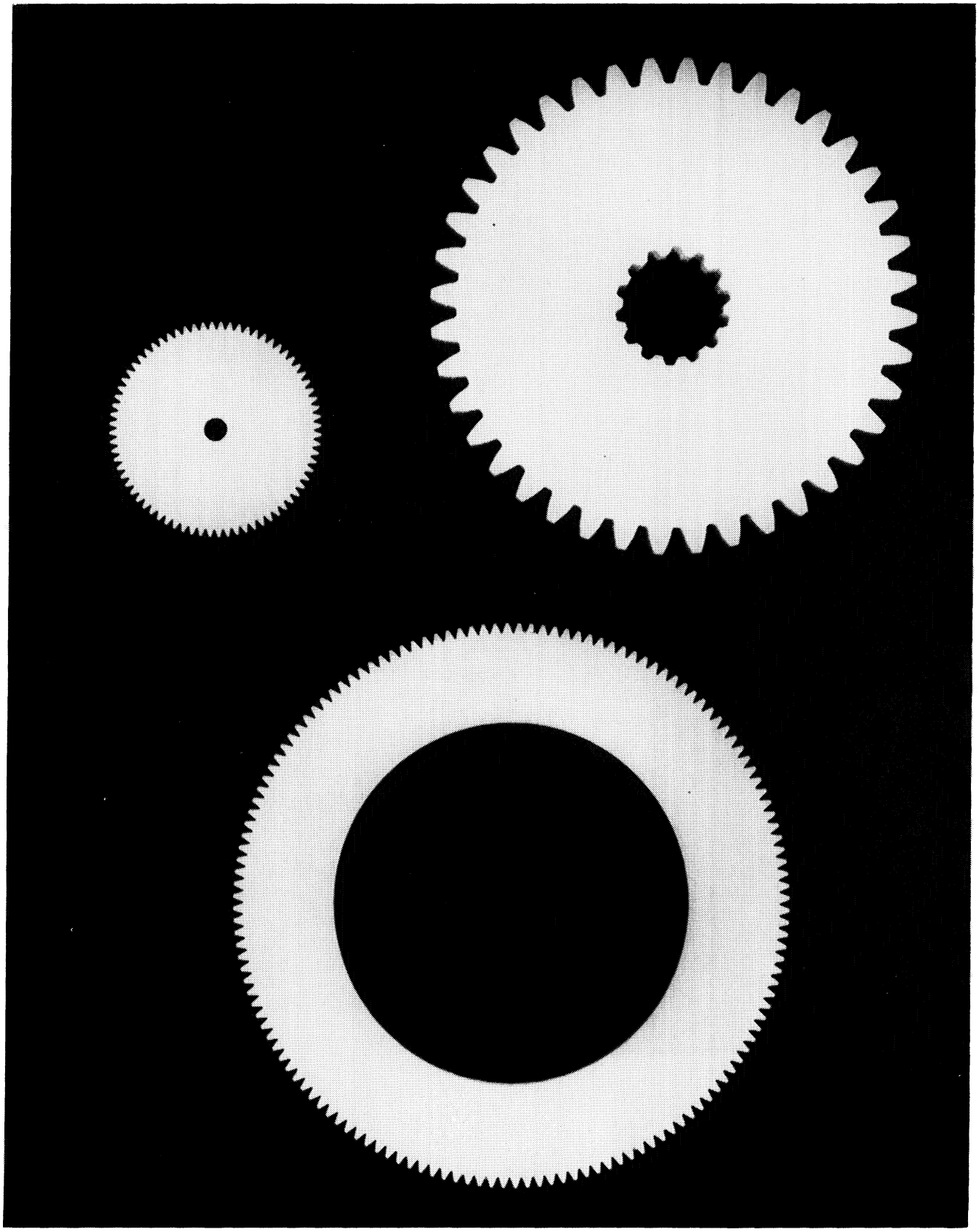


Fig. 1. Gears with teeth cut in molded "Zytel" 101.

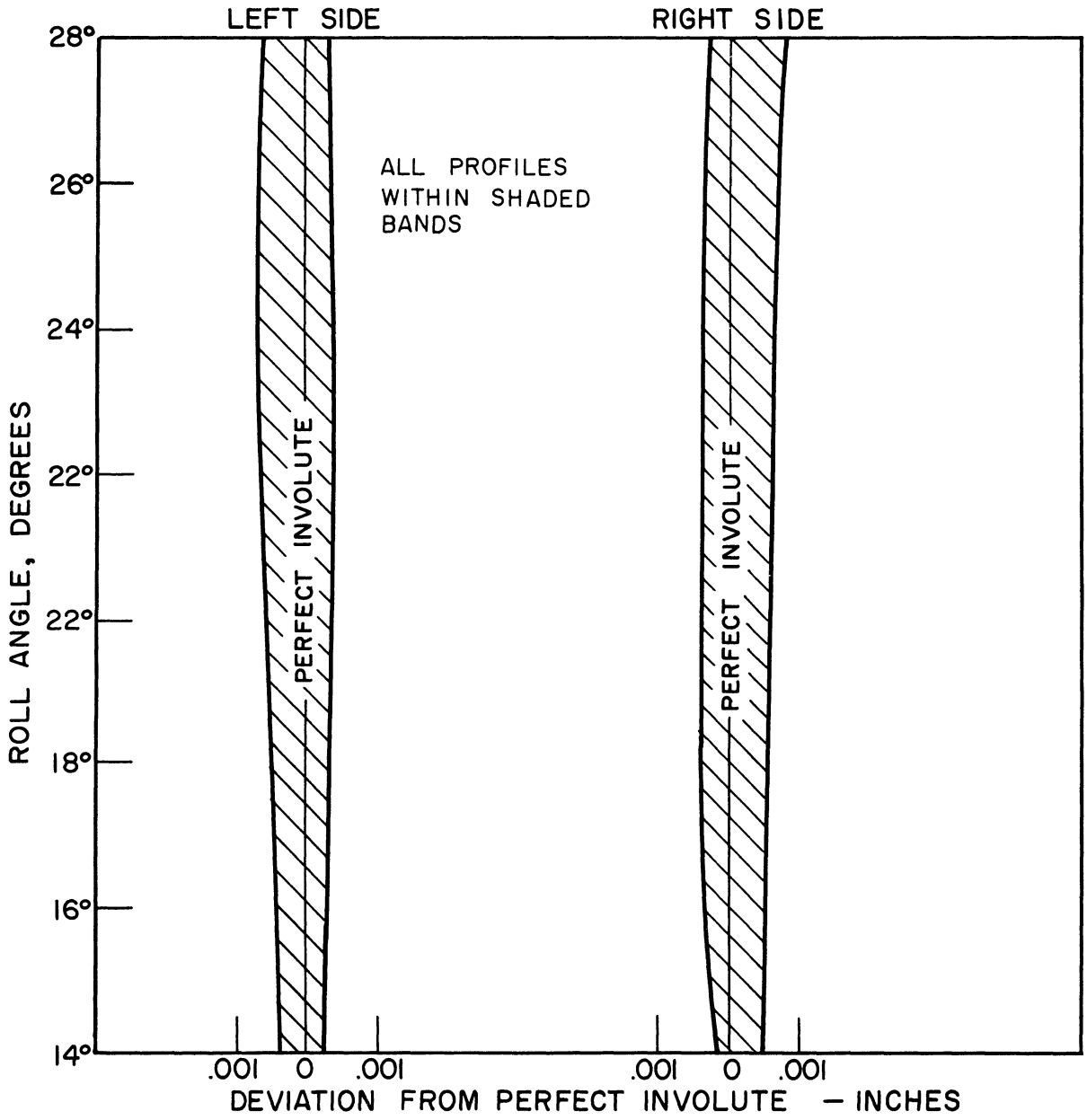


Fig. 2. Profile data for 16-pitch, hob-cut teeth.

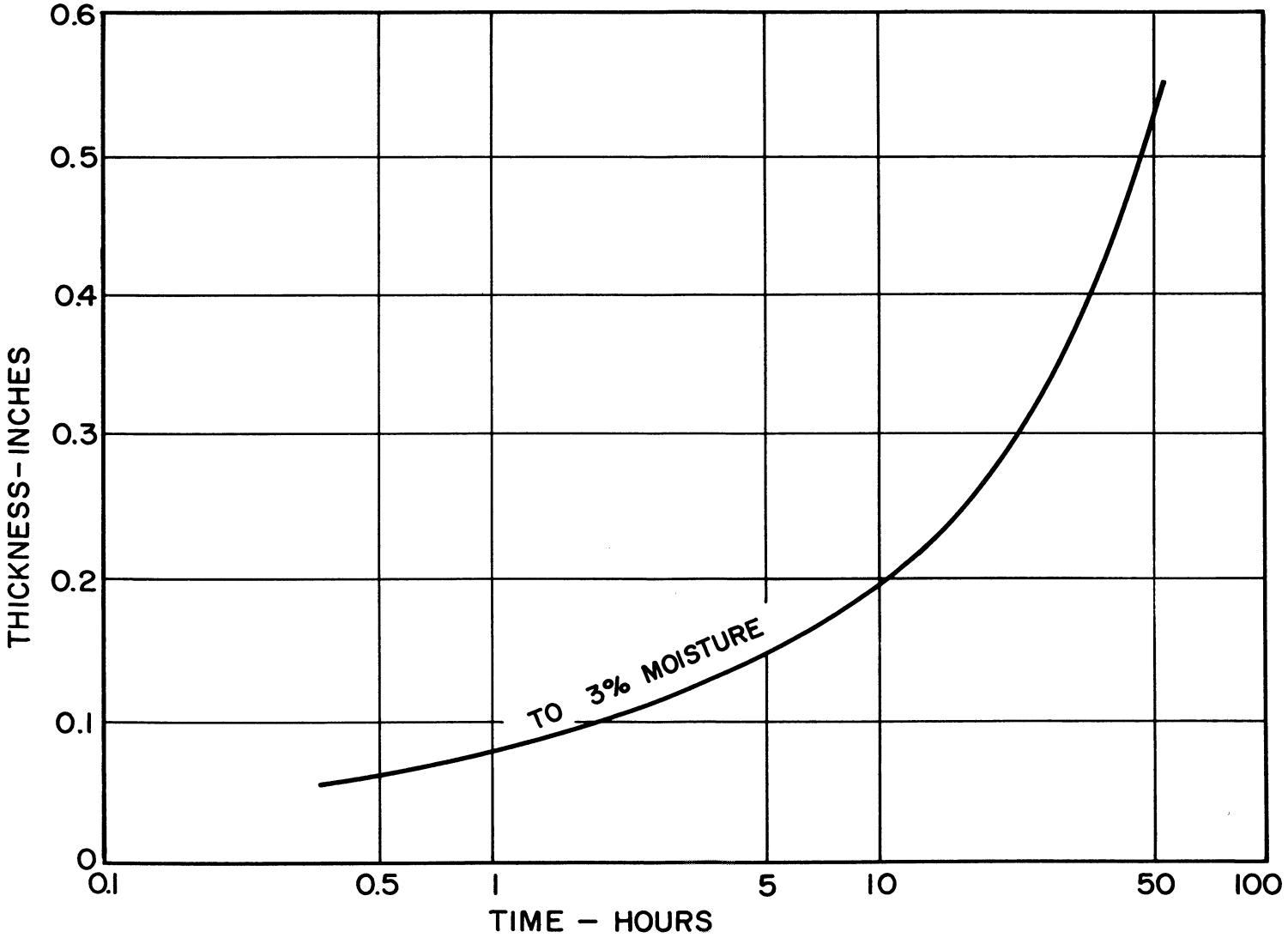
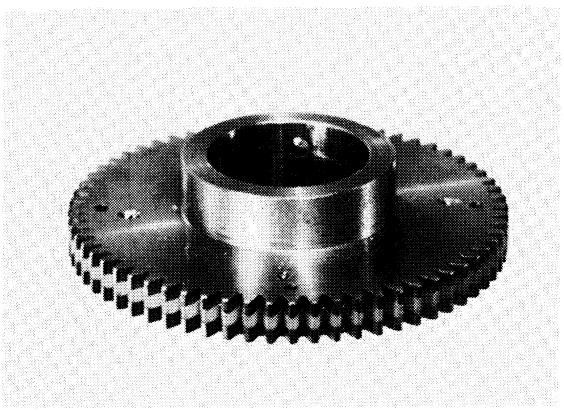
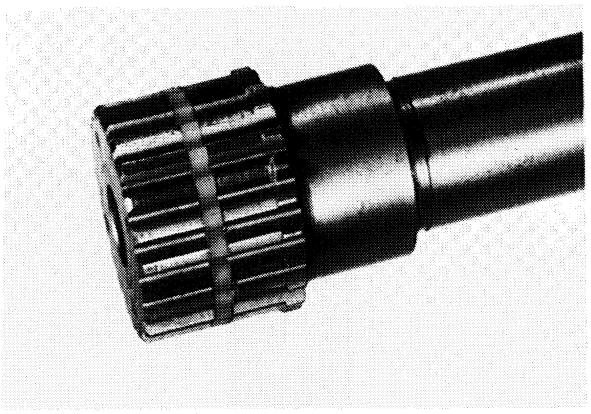


Fig. 3. Boiling times for "Zytel" 101 (E. I. du Pont de Nemours and Company, Incorporated).





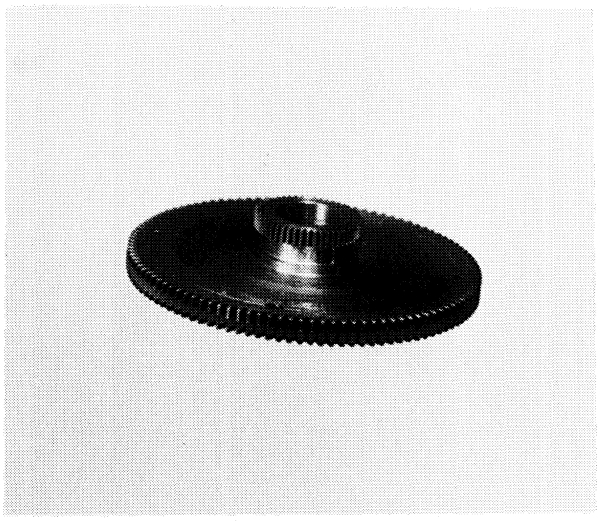


Fig. 4. Gears and spline with steel and molded "Zytel" 101 laminated construction ("Min-A-Lash" Construction, Dexter Machine Products, Incorporated).

without washer

with washer

Fig. 5. Burr formation with and without brass washer.