18.4 Strength Of Plastic Spur Gears

In the following text, main consideration will be given to Nylon MC901 and Duracon M90, However, the basic equations used are applicable to all other plastic materials if the appropriate values for the factors are applied.

18.4.1 Bending Strength of Spur Gears

Nylon MC901

The allowable tangential force F (kgf) at the pitch circle of a Nylon MC9O1 spur gear can be obtained from the Lewis formula.

$$F = m y b \sigma_b K_V \text{ (kgf)} \qquad (18\text{-}1)$$

where:
m = Module (mm)
y = Form factor at pitch point (see **Table 18-15**)
b = Teeth width (mm)
σ_b = Allowable bending stress (kgf/mm²) (see **Figure 18-1**)
K_V= Speed factor (see **Table 18-16**)

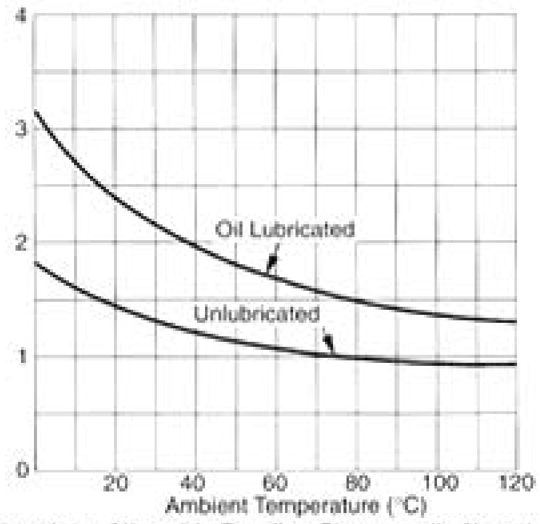

Fig. 18-1 Allowable Bending Stress, σ_b **(kgf/mm²)**

Table 18-15 Form Factor, y

Number of teeth	Form Factor		
	14.5º	20ºStandardTooth	20ºStubTooth
12	0.355	0.415	0.496
14	0.399	0.468	0.540
16	0.430	0.503	0.578
18	0.458	0.522	0.603
20	0.480	0.544	0.628
22	0.496	0.559	0.648
24	0.509	0.572	0.664
26	0.522	0.588	0.678
28	0.535	0.597	0.688
30	0.540	0.606	0.698
34	0.553	0.628	0.714
38	0.565	0.651	0.729
40	0.569	0.657	0.733
50	0.588	0.694	0.757
60	0.604	0.713	0.774
75	0.613	0.735	0.792
100	0.622	0.757	0.808
150	0.635	0.779	0.830
300	0.650	0.801	0.855
Rack	0.660	0.823	0.881

Table 18-16 Speed Factor, K_V

Lubrication	Tangential Speed (m/sec)	Factor K_V
Lubricated	Under 12	1.0
	Over 12	0.85
Unlubricated	Under 5	1.0
	Over 5	0.7

Duracon M90

The allowable tangential force F (kgf) at pitch circle of a Duracon M90 spur gear can also be obtained from the Lewis formula.

$$F = m y b \sigma_b \text{ (kgf)} \qquad (18\text{-}2)$$

where:
m = Module (mm)
y = Form factor at pitch point (see **Table 18-15**)
b = Teeth width (mm)
σ_b = Allowable bending stress (kgf/mm²)

The allowable bending stress can be calculated by **Equation (18-3)**:

$$\sigma_b = \sigma_b' \frac{K_V K_T K_L K_M}{C_S} \qquad (18\text{-}3)$$

where:
σ_b' = Maximum allowable bending stress under ideal condition (kgf/mm²) (see **Figure 18-2**)
C_S = Working factor (see **Table 18-17**)
K_V = Speed factor (see **Figure 18-3**)
K_T = Temperature factor (see **Figure 18-4**)
K_L = Lubrication factor (see **Table 18-18**)
K_M = Material factor (see **Table 18-19**)

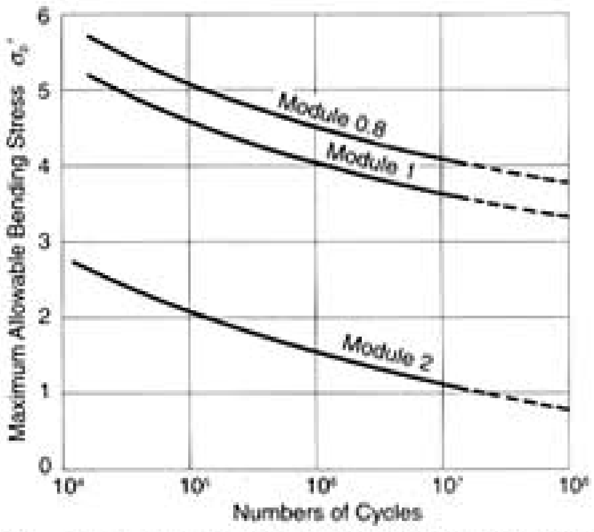

Fig. 18-2 Maximum Allowable Bending Stress under Ideal Condition, σ_b' **(kgf/mm²)**

Table 18-17 Working Factor, C_S

Types of Load	Daily Operating Hours			
	24 hrs./day	8-10 hrs./day	0.5 hrs./day	3 hrs./day
Uniform Load	1.25	1.00	0.80	0.50
Light Impact	1.50	1.25	1.00	0.80
Medium impact	1.75	1.50	1.25	1.00
Heavy Impact	2.00	1.75	1.50	1.25

Table 18-18 Lubrication Factor. KL

Lubrication	K_L
Initial Grease Lubrication	1
Continuous Oil Lubrication	1.5-3.0

Table 18-19 Material Factor, KM

Material Combination	K_M
Duracon vs. Metal	1
Duracon vs. Duracon	0.75

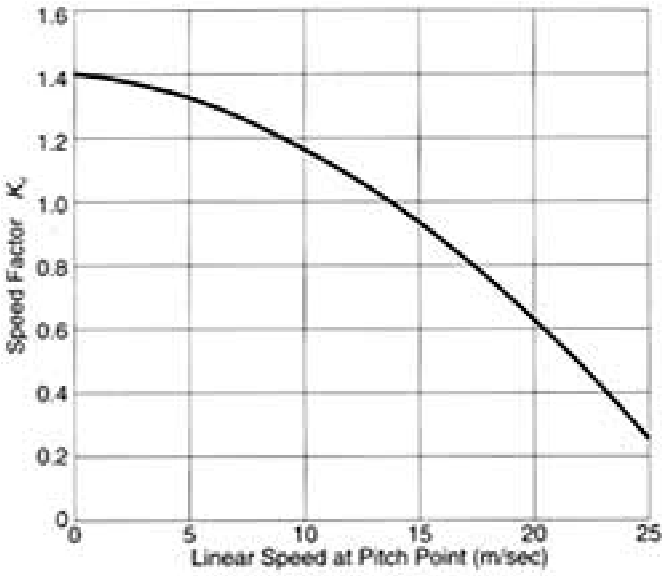

Fig. 18-3 Speed Factor, K_v

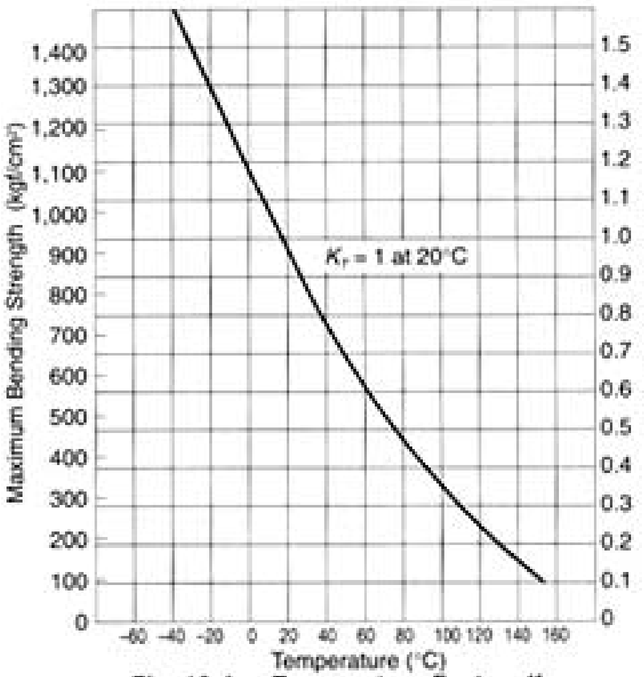

Fig. 18-4 Temperature Factor, K_T

Application Notes

In designing plastic gears, the effects of heat and moisture must be given careful consideration. The related problems are:

1. Backlash

Plastic gears have larger coefficients of thermal expansion. Also, they have an affinity to absorb moisture and swell. Good design requires allowance for a greater amount of backlash than for metal gears.

2. Lubrication

Most plastic gears do not require lubrication. However, temperature rise due to meshing may be controlled by the cooling effect of a lubricant as well as by reduction of friction. Often, in the case of high-speed rotational speeds, lubrication is critical.

3. Plastic gear with metal mate

If one of the gears of a mated pair is metal, there will be a heat sink that combats a high temperature rise. The effectiveness depends upon the particular metal, amount of metal mass, and rotational speed.

18.4.2 Surface Strength of Plastic Spur Gears

Duracon M90

Duracon gears have less friction and wear when in an oil lubrication condition. However, the calculation of strength must take into consideration a no-lubrication condition. The surface strength using Hertz contact stress, S_C, is calculated by **Equation (18-4)**.

$$S_c = \sqrt{\frac{F}{bd_1}\,\frac{u+1}{u}} \cdot \sqrt{\frac{1.4}{\left(\frac{1}{E_1}+\frac{1}{E_2}\right)\sin 2\alpha}} \quad (\text{kgf/mm}^2) \qquad \textbf{(18-4)}$$

where:

F = Tangential force on surface (kgf)
b = Tooth width (mm)
d_1 = Pitch diameter of pinion (mm)
u = Gear ratio $= z_2/z_1$
E = Modulus of elasticity of material (kgf/mm²) (see **Figure 18-5**)
α = Pressure angle

If the value of Hertz contact stress, S_C is calculated by **Equation (18-4)** and the value falls below the curve of **Figure 18-6**, then it is directly applicable as a safe design. If the calculated value falls above the curve, the Duracon gear is unsafe.

Figure 18-6 is based upon data for a pair of Duracon gears: m = 2, v = 12 m/s, and operating at room temperature. For working conditions that are similar or better, the values in the figure can be used.

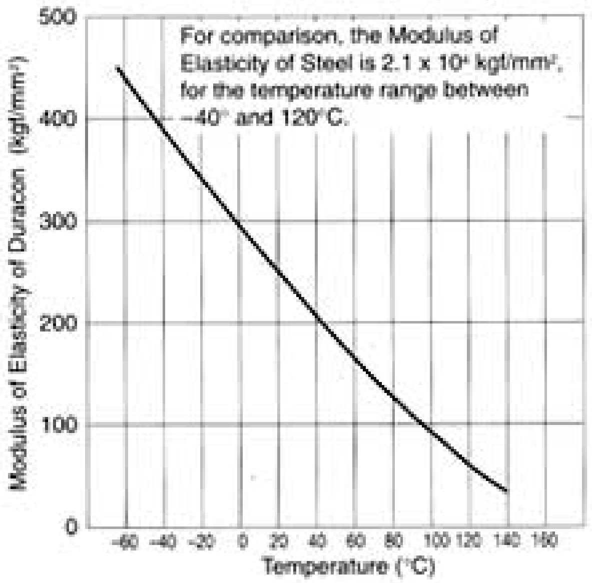

Fig. 18-5 Modulus of Elasticity in Bending of Duracon

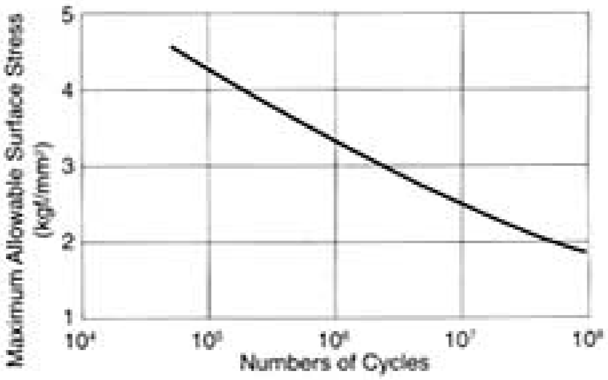

Fig. 18-6 Maximum Allowable Surface Stress (Spur Gears)

18.4.3 Bending Strength of Plastic Bevel Gears

Nylon MC901

The allowable tangential force at the pitch circle is calculated by **Equation (18-5)**.

$$F = m \frac{R_a - b}{R_a} y b \sigma_b K_V \qquad (18\text{-}5)$$

where:

y = Form factor at pitch point (by equivalent spur gear from **Table 18-15**)

$$z_v = \frac{z}{\cos\delta} \qquad (18\text{-}6)$$

where:

R_a = Outer cone distance

δ = Pitch cone angle (degree)

Z_V = Number of teeth of equivalent spur gear

Other variables may be calculated the same way as for spur gears.

Duracon M90

The allowable tangential force F(kgf) on pitch circle of Duracon M90 bevel gears can be obtained from **Equation (18-7)**.

$$F = m \frac{R_a - b}{R_a} y b \sigma_b \qquad (18\text{-}7)$$

where:

$$\sigma_b = \sigma_b' \cdot \frac{K_V K_T K_L K_M}{C_S}$$

and y = Form factor at pitch point, which is obtained from **Table 18-15** by computing the number of teeth of equivalent spur gear via **Equation (18-6)**.

Other variables are obtained by using the equations for Duracon spur gears.

18.4.4 Bending Strength of Plastic Worm Gears

Nylon MC901

Generally, the worm is much stronger than the worm gear. Therefore, it is necessary to calculate the strength of only the worm gear.

The allowable tangential force F (kgf) at the pitch circle of the worm gear is obtained from **Equation (18-8)**.

$$F = m_n y b \sigma_b K_V \text{ (kgf)} \qquad (18\text{-}8)$$

where: m_n = Normal module (mm)

y = Form factor at pitch point, which is obtained from Table 18-15 by first computing the number of teeth of equivalent spur gear using **Equation (18-9)**.

$$z_V = \frac{z}{\cos^3\gamma} \qquad (18\text{-}9)$$

Worm meshes have relatively high sliding velocities, which induces a high temperature rise. This causes a sharp decrease in strength and abnormal friction wear. This is particularly true of an all plastic mesh. Therefore, sliding speeds must be contained within recommendations of **Table 18-20**.

$$\text{Sliding speed } v_s = \frac{\pi d_1 n_1}{60000\cos\gamma} \quad \text{(m/s)}$$

Lubrication of plastic worms is vital, particularly under high load and continuous operation.

18.4.5 Strength of Plastic Keyway

Fastening of a plastic gear to the shaft is often done by means of a key and keyway. Then, the critical thing is the stress level imposed upon the keyway sides. This is calculated by **Equation (18-10)**.

$$\sigma = \frac{2T}{d\,l\,h} \quad (\text{kgf/cm}^2) \qquad (18\text{-}10)$$

where: σ = Pressure on the keyway sides(kgf/cm²)

T = Transmitted torque (kgf.m)

d = Diameter of shaft (cm)

ι = Effective length of keyway (cm)

h = Depth of keyway (cm)

The maximum allowable surface pressure of MC901 is 200 kgf/cm², and this must not be exceeded. Also, the keyways corner must have a suitable radius to avoid stress concentration. The distance from the root of the gear to the bottom of the keyway should be at least twice the tooth whole depth, h.

Keyways are not to be used when the following conditions exist:

- Excessive keyway stress
- High ambient temperature
- High impact
- Large outside diameter gears

When above conditions prevail, it is expedient to use a metallic hub in the gear. Then, a keyway may be cut in the metal hub.

A metallic hub can be fixed in the plastic gear by several methods:

- Press the metallic hub into the plastic gear, ensuring fastening with a knurl or screw.
- Screw fasten metal discs on each side of the plastic gear.
- Thermofuse the metal hub to the gear.

18.5 Effect Of Part Shrinkage On Plastic Gear Design

The nature of the part and the molding operation have a significant effect on the molded gear. From the design point of view, the most important effect is the shrinkage of the gear relative to the size of the mold cavity.

Gear shrinkage depends upon mold proportions, gear geometry, material, ambient temperature and time. Shrinkage is usually expressed in millimeters per millimeter. For example, if a plastic gear with a shrinkage rate of 0.022 mm/mm has a pitch diameter of 50 mm while in the mold, the pitch diameter after molding will be reduced by (50)(0.022) or 1.1 mm, arid becomes

Table 18-20 Material Combination and Limits of Sliding Speed

Material of Worm	Material of Worm Gear	Lubrication Condition	Sliding Speed
"MC" Nylon	"MC" Nylon	No Lubrication	Under 0.125 m/s
Steel	"MC" Nylon	No Lubrication	Under 1 m/s
Steel	"MC" Nylon	Initial Lubrication	Under 1.5 m/s
Steel	"MC" Nylon	Condition Lubrication	Under 2.5 m/s