# Design and Development of Polyamide 46 (PA46) Plastic Spur Gear in Engine Applications

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***Abstract - This paper deals with the idea of gear designing and development of steel and plastic gear transmission for automobile applications. Basically the driver and driven gear material plays important role for the better wear performance. When metal gears are replaced by plastic gears in automobiles, appliances and machineries due to its advantages of low cost, lightweight, low noise, self-lubrication, less wear, economic considerations, simple design and high production rate in manufacturing. Due to thermal wear nylon 6 and nylon 66 both gears failed, hence to overcome the problem of these gear the PA 46 is better option due to its superior properties and it also meet extreme performance challenges. Beam strength of the gear & static tooth load is calculated with help of Lewis equation & dynamic tooth load & wear tooth load is calculated with help of Buckingham equation.***

***Keywords: PA 46, Buckingham equation, Lewis equation.***

## I. INTRODUCTION

With the rapid development of macromolecule polymer composite materials in industry for plastic gears, as new materials, have been widely used. Combined with the plastic gear has many advantages, such as light weight, low noise, resistance corrosion, small inertia and less cost and so on, plastic gears not only can be an alternative to metal gears in many areas, but also can be used in many areas where metal gears cannot be used. Plastic gear applications increasingly become a global trend in the gear industry [1]. Now day's In automotive application plastic gears are commonly used. In mechanical power transmission gearing plays most important role and are generally used for power as well as motion transmission and in most industrial rotating machinery and work under different power, speeds and loads. Due to their high degree of reliability, less weight, compactness, and low cost, it is possible that gears will predominate as the most effective means of transmitting power in future engines. In addition, the rapid shift in the industry from heavy industries such as shipbuilding to industries such as automobile manufacture and office automation tools will necessitate a refined application of gear technology. Historically, they were limited to very low power transmissions in printers, clocks and lawn sprinklers. Today's stronger as well as consistent polymers in engineering and its better control of the molding process, now it makes possible to produce larger volume with precise gears that are compatible with higher horsepower. It also opens new opportunities for smaller and more efficient transmissions in many products.[2]

The driver and driven material plays a key role in the wear performance. When nylon 66 is used as governor gear i.e driven and steel gear i.e engine crank shaft used as as driver. The nylon 66 material failed with thermal properties where temperature reaches more than 295° C. Hence to overcome the limitations of Nylon 66 and PA 46 may find substitute due to their superior thermal properties.

## II. NEED OF THIS REASEARCH WORK

A lot of work has been carried out on the wear analysis of metal gear. Whereas very few researchers have worked on the study of wear behavior of plastic gear and nobody has touched to the topic undertaken for study [2]. Hence the design and development of plastic (PA46) gear is undertaken for study.

In this paper, we will discuss about single cylinder air-cooled engine having 7.5 Hp power. In which governor gear used to operate governor linkage which controls engine speed according to acceleration, material is En8 (42 CrMo4) ,manufacturing root is forging. Our proposal is to convert this metallic governor gear to plastic PA 46.Governor gear is driven by crank shaft which is rotating at 3900 rpm.

The focus of the current research is to compare the following points:-

- To select the more reliable material for plastic gear.
- To design the plastic spur gear analytically so that it should meet the requirement of existing Metal gear
- To develop PRO-E models of spur gear.

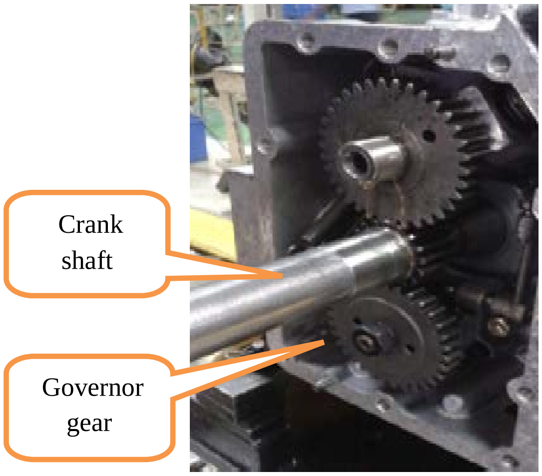


Fig. 2.1 Governor gear mounting arrangement

## III. PREVIOUS WORK

It was found that the surface temperature was the dominant factor influencing the wear rate. Performance of molded gear is important for economic reasons because it can be mass produced at a fraction of the cost compared to machine gears. In different operating conditions accuracy of molded gears is very important in now days. The study of molded gear performance is important for economic reasons because it can be mass-produced at a fraction of the cost compared to machined / metal gear [2].

The automotive industry is on the brink of a revolution, and the plastics industry suspended to play a major role. The real plastic revolution in automotive industry began in 1950 when thermoplastics made their debut with ABS then polyamide, polyacetal and polycarbonate together with introduction of alloys and blends of various polymers [3]. Much research was done in 1970s and 1980s, especially in Germany, on predominantly polyacetal (POM) and polyamide (PA) gears. These experimental investigations focused on measuring the load capabilities for various gears under changeable conditions. These studies typically used for the normalized force versus the number of cycles to failure. In this approach, the gear module and other geometry factors are still important variables. Relatively little attention was paid to stress analysis and wear mechanisms and how these changed under different conditions. The standardized calculations of ISO 6336 and DIN 3990 were used to calculate indicative stresses, but it was understood that many discrepancies existed between "metal" theories and "plastic" practice. Specific plastic gear standard was developed by VDI (VDI 2545) in the 1980s, and it was withdrawn in 1996 for unknown reasons, but this standard is still commonly used.

However, this design has not accepted although substantial research has conducted in the field of plastic gears. Today's plastic gear designs still seem to be based on experience and comparative calculations of metal gear standards. The differences between metal and plastic gears and how they have an effect on kinematics, wear and stresses are still rather undefined. To find answers to these questions, the results of semi-analytical methods (e.g., ISO standards and KissSoft) and finite dement analysis was begun, in addition to an wide-ranging experimental program on plastic gears [4]

## IV. MATERIAL SELECTION

To achieve their intended performance of gear, durability and reliability, the selection of a suitable gear material is very essential. In plastic engineering a vast knowledge and experience has been accumulated. With economy and in the interest of time, usually a well-known material will effectively suit the user’s purpose. PA 46 is a generic designation for a family of synthetic polymers known generically as aliphatic polyamides.

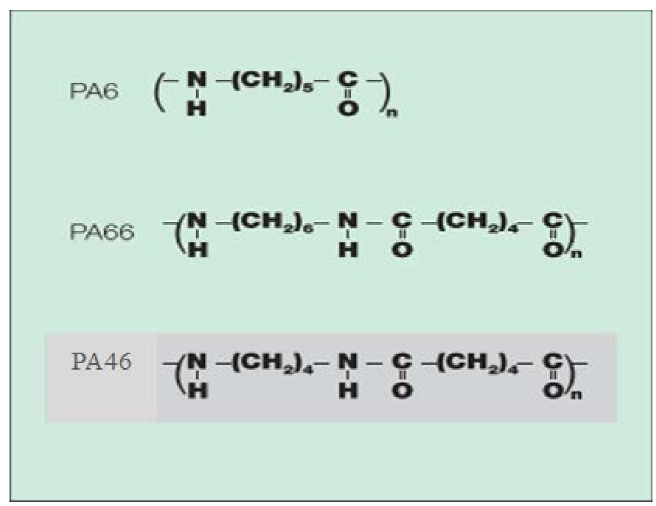


Fig. 4.1Governor gear mounting arrangement

The automobile sector is marked by a constraint shift towards plastics. Especially, Thermoplastics has some wider range of applications in it. The materials used for the manufacture of ears depend upon the strength and service conditions like wear and noise etc. Weight reduction can be achieved primarily by the introduction of good material, design optimization and enhanced manufacturing processes. The plastic materials have little thermal and electrical conductivity and corrosion resistance, easy to produce complex shapes, extensive choices of appearance, colors as well as transparencies. By introduction of plastic materials it was made to reduce the weight of the rotating spares without any reduction on load carrying capacity and stiffness. The final selection should be based upon an understanding of material properties and application requirements.

In PA46 and PA66 there are some similarities between the molecular structure, the higher number of amide groups per given chain length and the symmetrical chain structure of PA46 result in the higher melting temperature of 295° C, a higher crystallinity, and faster rate of crystallization [5].

PA46 crystallininty is approximately 70%, compares with 50% for PA66. This results in high heat distortion temperature of 190°C for unreinforced PA46l and 290°C for glass fibre reinforced PA46. These features give PA46 a technical edge over other engineering plastics like polyamide 6 and 66, polyesters and semi-aromatic polyamides (PPA's) with regard to mechanical properties at elevated temperatures, friction and wear behaviour and, due an advantage in productivity improvement.

PA46 excellent properties (see Table1) lead to important advantages for the customer such as cost reduction, longer lifetime and high reliability. PA46 bridges the gap between conventional engineering plastics such as PA6, PA66, PET, and exotic materials such as LCP, PPS and PEEK.[5]

TABLE 1.TYPICAL PROPERTIES DEPENDENT ON STRUCTURE

| Properties | PA6 | PA66 | PA 46 |
|---|---|---|---|
| Melting Point (°C) | 225 | 265 | 295 |
| Density (Kg/M$^3$) | 1140 | 1140 | 1180 |
| Crystallization Rate<br>- At 200 $^0$c (Min$^{-1)}$<br>$^-$ At 230 $^0$c | 0.2<br>0 | 6<br>0.7 | >15<br>10 |

Benefits for both moulders and end user include

- resistance to high temperatures
- 30% productivity increase of moulding equipment
- More design choice due to the excellent mechanical properties and good mould flow behaviour
- No post treatment to the absence of flash.
- Retooling is not required when switching from PA6, PA66 or polyesters [5].

## V. DESIGN METHODOLOGY

The design of spur gear is done by using Lewis and Buckingham equations. The theoretical design calculations are performed using the input parameters such as power of engine, pinion speed, gear ratio, pressure angle, Speed of Pinion, Gear Ratio [6].

TABLE 2.SPECIFICATIONS

| S. No. | Parameter | Driver gear (Metallic Cr. Shaft) | Driven gear (Plastic governor gear) |
|---|---|---|---|
| 1 | T = No. of teeth | 16 | 32 |
| 2 | N = Speed (rpm) | 3900 | 1950 |
| 3 | b = Face width (mm) | - | 10 |
| 4 | m = Module in (mm) | - | 2 |
| 5 | $\sigma_o$= Allowable static stress (MPa) | 210 | 59 |
| 6 | $C_v$ = Velocity factor | - | 0.349 |
| 7 | $v$= Pitch Line velocity (m/s) | 13.06 | 6.53 |
| 8 | C = Dynamic factor in (N/mm) | 114 | 79 |
| 9 | $\sigma_e$= Flexural endurance limit (MPa) | 84 | 32 |
| 10 | Q = Ratio Factor | 0 | 66 |

**1. Tangential load acting at the tooth ($W_T$)by Lewis equation,**

$W_T = \sigma_w b\, p_c\, y = \sigma_w\, b\, \pi\, m\, y$

$= (\sigma_o C_v)\, b\, \pi\, my$

Note:

When the pinion and the gear are made of different materials, then the product of ($\sigma_w \times y$) or ($\sigma_o \times y$) are the deciding factors. The Lewis Equation is used for which ($\sigma_w \times y$) is less [6].

$y$ = Lewis form factor or tooth form factor (for 20$^0$ full depth involute system)

$$y = 0.154 - \frac{0.912}{T}$$

$$y_{\text{Gov gear}} = 0.154 - \frac{0.912}{32} = 0.125$$

$$y_{\text{cr.shaft}} = 0.154 - \frac{0.912}{16} = 0.097$$

$\therefore$ ($\sigma_o \times y$) for Cr. Shaft = 210 X 0.097

= 20.37

$\therefore$ ($\sigma_o \times y$) for Gov. Gear = 59 X 0.125

= 7.375

Value of ($\sigma_o \times y$) for governor gear is less

So applying Lewis equation to governor gear

$\therefore W_T = 59 \times 0.349 \times 10 \times \pi \times 2 \times 0.125$

$$\boxed{W_T = 161.72 \text{ N.}}$$

2. **Dynamic load ($W_D$) on the tooth by Buckingham equation**

$$W_D = W_T + W_I$$

$$= W_T + \frac{21v\,(b.C+W_T)}{21v+\sqrt{b.C+W_T}}$$

$$= 161.72 + \frac{21\times6.53\,(10\times79+161)}{21\times6.53\times\sqrt{10\times79+161}}$$

$$\boxed{W_D = 192.55 \text{ N}}$$

3. **Static tooth load ($W_S$) by Lewis equation**

$$W_S = \sigma_e\, b\, p_c\, y$$

$$= \sigma_e\, b\, \pi\, m\, y$$

$$= 32 \times 10 \times \pi \times 2 \times 0.125$$

$$\boxed{W_S = 251.3 \text{ N}}$$

As $W_S > W_D$

Then the Design is safe.

**Wear tooth load ($W_W$) by Buckingham equation**

$$W_W = D_p . b . Q . k$$

$$= 64 \times 10 \times 0.66 \times 1$$

$$\boxed{W_W = 422.4 \text{ N}}$$

As $W_W = 422.4$

As $W_W > W_D$

The given design is safe.

## VI. SIMULATION RESULTS

The high crystallization rate of PA46 results in the formation of many small spherulites. This explains the superior toughness of PA 46 compared to other engineering plastics, resulting into unique combination of toughness and high heat resistance (see Fig 6.1). The combination of small spherulites and high crystallinity resulted in excellent fatigue behaviour [5].

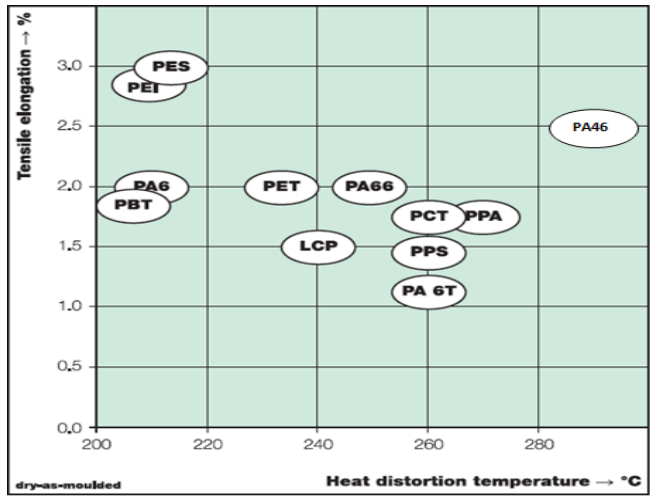


Fig. 6.1 Positioning of 30% GF reinforced, flame retardant thermoplastics

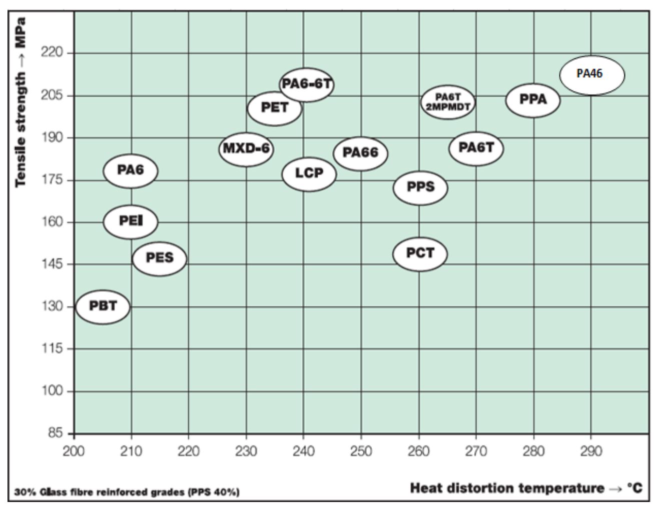


Fig. 6.2 Tensile strength vs. Heat resistance of PA46 and other engineering plastics.

Due to its unique combination of excellent mechanical properties and high heat resistance, (see fig 6.2). PA46 bridges the gap between conventional engineering plastics such as PA6 ,PA66, and polyesters and more exotic materials such as LCP, PPS , PSU, PEEK, PES, PEI.

The high crystallinity and fine crystalline structure of PA46 leas to fatigue resistance superior to that of most other engineering & heat resistance plastics.(see fig 6.3). The fatigue resistance of PA46 is much better than that of PPA , PPS and PA66. For gears and chain tensioners fatigue resistance is mainly important [5].

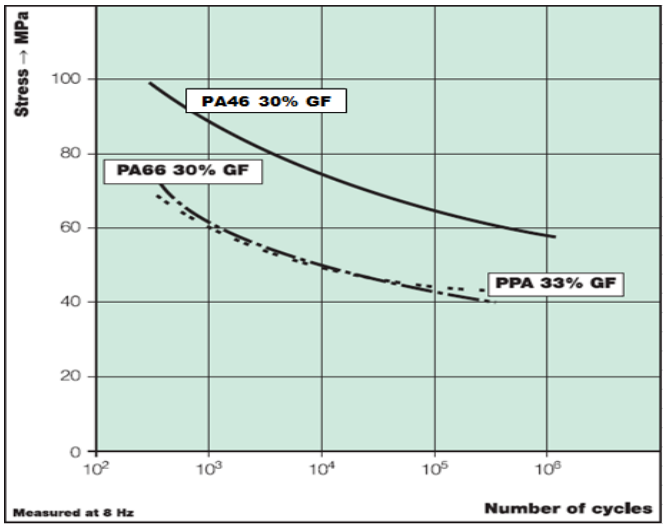


Fig. 6.3 Fatigue resistance at 140° C of glass fibre reinforced engineering plastics

PA46 also has excellent abrasion resistance and outperforms many other engineering plastics under most conditions. Fig 6.4 shows the comparison between PA46, PA66 and POM according to the taber Abrasion test.

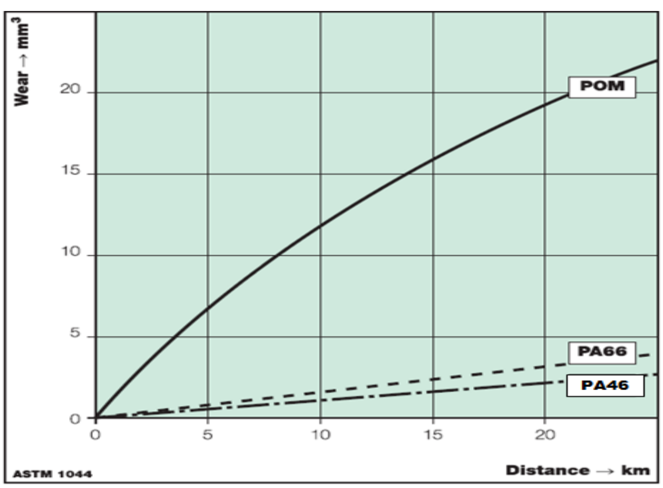


Fig. 6.4 Taber Abrasion resistance.

Polyamides are well known for their resistance to a wide range of chemicals. It is resistance to oil & greases is excellent especially at higher temperature (see fig 6.5) automotive industry and for other industrial applications such as gears and bearings [5].

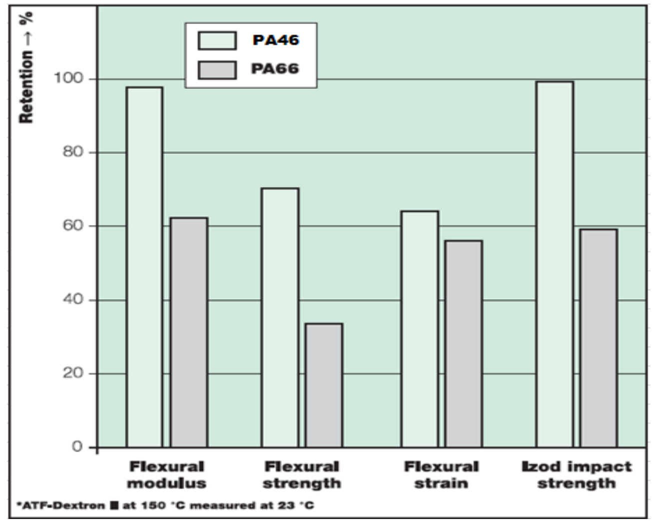


Fig. 6.5 Retention of mechanical properties after 1000 hrs. Immersion in oil.

## VII. Conclusion

This paper suggests appropriate plastic material selection, and gear design. Plastic gear can be act as a alternate for metallic gear in engines to get advantages of lightweight, low noise, less wear, self-lubrication, less cost, economic considerations, simple design with high production rate in manufacturing. It can help to establish plastic gear standard and it is beneficial for the design and manufacturing of plastic gears.

## VIII. Future Scope

PA 46 material can be used for application where temperature is more than 290° C .PA 46 is higher grade material in polyamides it can be used where nylon 66 material fails for thermal analysis. Engine components like camshaft, thrust washer, rocker cover, governor bell, oil pan can be converting to PA 46 material, which are continuously in contact with oil and greases.

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