Electron-Beam-Irradiated Cross-Linked Gears with High Durability

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We have applied cross-linking technology to plastic materials through high-energy electron-beam irradiation to obtain gears with high durability. Sumitomo Electric Fine Polymer's Teralink cross-linked gears, which use polyamide 66 as their base polymer, exhibit a three-fold improvement in durability in terms of the amount of tooth load that they can withstand compared to gears made of the same base polymer.

Keywords: electron beam irradiation, injection molding, plastic, fatigue strength, gear

1. Introduction

The market for sliding members such as gears, washers and bearings made from plastic materials instead of metals is growing rapidly, especially in applications where weight reduction becomes a necessity. For these plastic parts, mechanical strength is an issue that needs to be addressed.

Polyacetals and polyamides account for the majority of engineering plastics used for gears. In terms of polyamides, polyamide 66 is characterized by its superb strength, friction and wear resistance, and chemical resistance, and is low cost. Thus, polyamide 66 is widely used for various parts in the industrial equipment field. It is also well known that this material can be cross-linked by an electron beam irradiation process.[1]

Sumitomo Electric Industries, Ltd. manufactures and sells Teralink engineering plastic parts whose fatigue strength is improved by taking full advantage of its electron beam irradiation technology. This paper focuses on the improvement of gear performance owing to the cross-linking of polyamide 66.

2. Manufacturing Method

Figure 1 shows the manufacturing method of Teralink electron beam-irradiated cross-linked plastic parts.

To impart cross-linking properties to a thermoplastic polymer by irradiating it with an electron beam, a special monomer is mixed homogeneously using a double-shaft mixer or other equipment to form cylindrical pellets. Next, these pellets are molded into the product shape using an injection molding machine. Finally, the product is irradiated with a high-energy accelerated electron beam to form a three-dimensional mesh structure in the polymer.

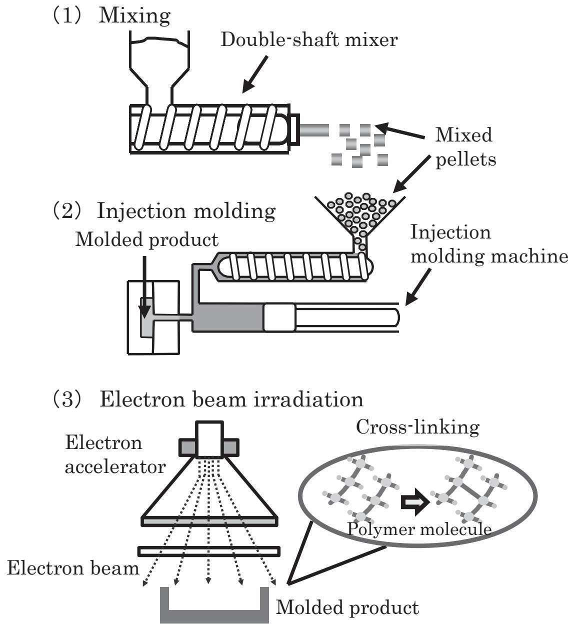


Fig. 1. Manufacturing process of electron beam-irradiated cross-linked molded products

3. Basic Properties

For dumbbell specimens of cross-linked polyamide 66 derived from the abovementioned method, we measured the basic properties such as tensile strength, elongation, bending strength, bending elastic modulus, charpy impact strength, and specific gravity.

The base resin of the same grade with that of the cross-linked polyamide 66 was molded to produce polyamide 66 dumbbell specimens, and their basic properties were measured.

The properties of polyamides change depending on the condition (dry or moist). Table 1 shows the results

Table 1. Basic properties of dry samples

	Unit	Polyamide 66	Cross-linked polyamide 66
Tensile strength	MPa	85	98
Elongation	%	7	31
Bending strength	MPa	113	134
Bending elastic modulus	GPa	2.8	3.2
Charpy impact strength	kJ/m^2	3	4
Specific gravity	—	1.1	1.1

using dry samples, and Table 2 shows the results using moist samples (saturated moisture absorption at 25°C and 60% humidity).

Table 2. Basic properties of moist samples (saturated moisture absorption) at 25°C and 60% humidity

	Unit	Polyamide 66	Cross-linked polyamide 66
Tensile strength	MPa	61	77
Elongation	%	232	54
Bending strength	MPa	54	73
Bending elastic modulus	GPa	1.3	1.8
Charpy impact strength	kJ/m^2	11	16
Specific gravity	—	1.1	1.1

In terms of dry samples, the tensile strength, bending strength, and bending elastic modulus of the cross-linked polyamide were 1.15 times, 1.19 times, and 1.14 times higher, respectively, than those of polyamide 66. The same trend was observed for the moist samples (saturated moisture absorption at 25°C and 60% humidity).

Cross-linking is considered to have increased the binding of the molecules to form a three-dimensional mesh structure.

4. Fatigue Strength

4-1 Dumbbell fatigue strength

Gears are subject to fracture due to repeated stress at or below the tensile strength and bending strength at certain intervals. We measured the number of cycles until fracture occurred for each stress using dry tensile dumbbell specimens and estimated the stress (fatigue strength) at which fracture would occur after an infinite number of cycles. The results are shown in Fig. 2.

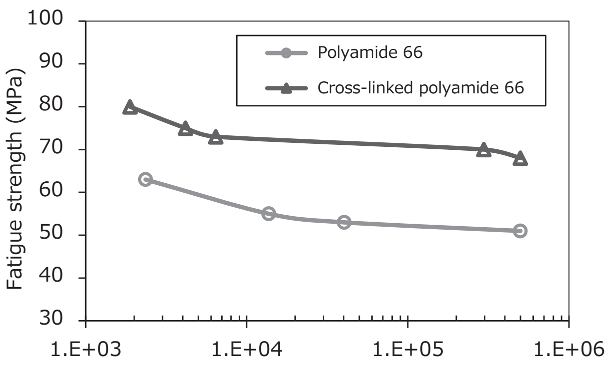


Fig. 2. Measurement results of dumbbell fatigue strength

The fatigue strength of polyamide 66 and cross-linked polyamide 66 was estimated at 51 MPa and 68 MPa, respectively. Cross-linking improved the fatigue strength 1.29 times.

The result shows that the fatigue strength changed more significantly than the tensile strength, which improved only by 1.15 times as discussed in the basic properties.

4-2 Gear fatigue test

We fabricated two types of gears from cross-linked polyamide 66 based on the procedure shown in Fig. 1 (one type with face width: 5 mm, module: 1, and number of teeth: 30; the other type with face width: 5 mm, module: 1, and number of teeth: 31). We also fabricated the same gears from polyamide 66 and polyacetal by injection molding.

Gears of the same material were engaged with each other and were allowed to rotate for 100 hours without lubrication at the torque of 35 N·cm (tooth load: 4.5 N/mm), 616 rpm (pitch circumferential speed: 60 m/min) to conduct a fatigue test.

The weight decrease rate and base tangent length*[1] were used as the evaluation indices to verify the decrease rate. The results are presented in Fig. 3.

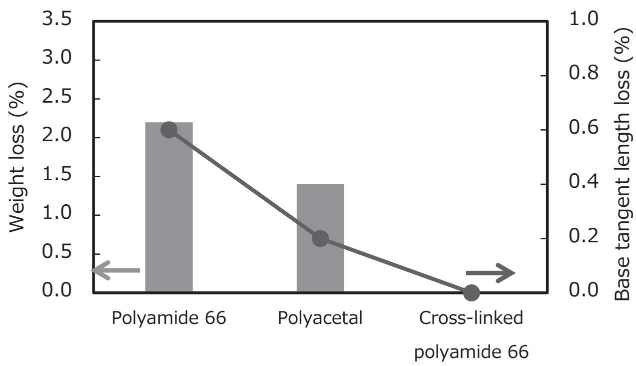
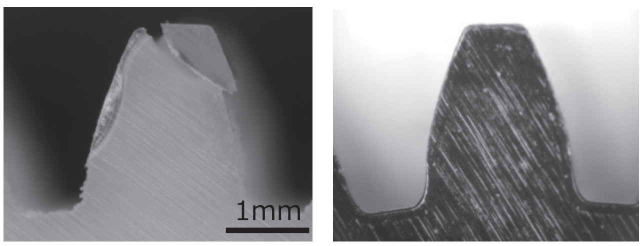


Fig. 3. Results of the gear fatigue test

The weight of polyamide 66 decreased by 2.2%, while the weight of cross-linked polyamide 66 did not decrease at all. Photo 1 shows the image of the gear tooth tip captured after a fatigue test. The image shows that the gear made of cross-linked polyamide 66 did not wear at all and is characterized by high wear resistance.



Polyamide 66 Cross-linked polyamide 66

Photo 1. Gear tooth tip after the fatigue test

4-3 Gear fatigue strength

Next, we conducted fatigue tests under the same conditions as described in 4-2 by applying multiple tooth flank loads. We investigated the load at which the weight decrease rate reached 0.5% or more or the gears broke, and this load was defined as the limit tooth load.

The limit tooth load was calculated for cross-linked polyamide 66, polyamide 66, polyacetal, and super engineering plastic (PEEK).*2 Figure 4 shows the results.

The limit tooth load of cross-linked polyamide 66 was 3.8 times and 3.3 times greater than that of polyamide 66 and polyacetal, respectively. Moreover, it was close as 0.68 times that of PEEK. These results indicate that cross-linked polyamide 66, with the limit tooth load being over three times higher than those of general-purpose gear materials and nearly 70% of PEEK, is an excellent alternative to these engineering plastic materials.

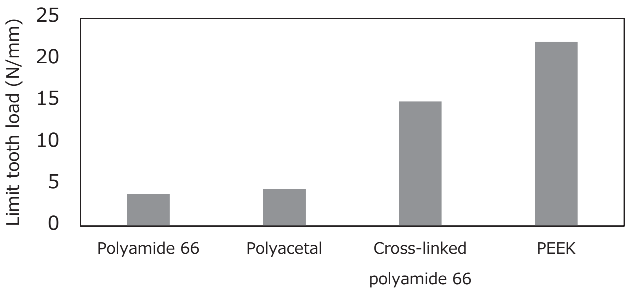


Fig. 4. Limit tooth load

5. Usage Examples

Cross-linked polyamide 66 is being used in wide variety of applications including industrial equipment parts and gears in electric bikes The material is expected to be used to meet the needs to design smaller gears than those made of polyacetal and polyamide 66, reduce the cost of gears made of super engineering plastics, and reduce the weight of gears currently made of metals.

Sumitomo Electric has also recently developed cross-linked heat-resistant grades using polyamide 46, which is characterized by a higher heat resistance than polyamide 66.

6. Conclusion

This paper presented the characteristics of cross-linked polyamide 66, which is derived by cross-linking polyamide 66 through the utilization of electron beam irradiation technology.

When cross-linked polyamide 66 is used for gears, the fatigue strength can be significantly improved. Cross-linked polyamide 66 is expected to help reduce the volume of general-purpose gear materials and facilitate the shift from metal parts to plastic parts from the viewpoint of weight reduction.

Technical Terms

*1 Base tangent length: Base tangent length refers to the gear tooth thickness measured across multiple teeth using a gear tooth micrometer.

*2 PEEK: PEEK is the abbreviation for polyetheretherketone resin.

Reference

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