Bio-based UV-Curable Optical Fiber Coatings: Bridging Performance and Sustainability

Wanyu Liao, Noriyasu Shinohara
Japan Fine Coatings Co., Ltd, Kanagawa Research & Development Center (KRDC)
Kawasaki, Kanagawa, Japan
+81-44-328-5210 · Wanyu.liao@covestro.com

Abstract

In response to the important global trend of reducing carbon footprint, this study has taken a step forward in the application of bio-based materials in UV-curable optical fiber coating systems through oligomer synthesis and formulation development. In secondary coating oligomer synthesis, we increased the biomass content of oligomers up to 1.5 times that of previously developed products. In primary coating oligomer development, we maintained the biomass content ratio while addressing previous limitations in flowability and coloration.

We then confirmed the key characteristics of bio-based formulations, Young's modulus and viscosity. For secondary coatings, we report several formulations within the practical performance range, some demonstrating the possibility of expanding to meet various application requirements. For primary coatings, we developed multiple transparent and colorless formulations, overcoming the coloration issues in previous research. Among the newly developed formulations, some are within the practical range while others are outside. Formulations outside the range have higher biomass content, providing new research directions for the bio-based transformation of optical fiber coating materials. These results suggest that through further formulation optimization, a better balance between performance requirements and sustainability goals may be achievable..

Keywords: UV curable coatings; Optical fiber coatings; Biomass

1. Introduction

Standard telecommunication optical fibers consist of a 125 µm diameter glass core and cladding surrounded by polymer coatings that increase the total diameter to 250 µm, with these coatings constituting 75% of the fiber's volume. The dual-layer coating system—featuring a flexible inner "primary" coating and rigid outer "secondary" coating—provides essential protection for the fragile glass, minimizes light transmission losses, and ensures consistent performance across the diverse global environments where optical fibers are deployed, from deserts and oceans to underground installations and urban networks.

In response to global carbon footprint reduction initiatives, our strategic objective is to incorporate biomass and renewable raw materials throughout our production processes. We consider bio-based products essential for achieving permanent emissions reductions and enhancing industry sustainability, making the evaluation of biomass raw materials for UV-curable optical fiber coatings a significant research direction aligned with Sustainable Development Goals. This paper examines the potential application of biomass-derived materials in our UV-curable optical fiber coating systems.

2. Experiment

2.1 Materials

All samples of primary and secondary coatings consisting of urethane acrylates were prepared in our laboratories. Primary and secondary coatings were designed to perform the high inner cure degree and the high surface cure degree, respectively.

2.2 Measurement of Viscosity

The viscosity at 25°C. was measured using a BH8 rotator.

2.3 Preparation of Test Specimens

Liquid UV curable coatings were applied on a glass plate with a certain thickness using an applicator bar.

These liquid coatings were cured by UV lamps at a dose of 1 J/cm2 in the air. The cured coatings were allowed to stand for 12 hours or more at a temperature of 23°C and a relative humidity of 50%, and subjected to the following tests.

2.4 Measurement of Young's Modulus

Young's modulus at 23°C was measured by using a tensile machine at tensile speed of 1mm/min. Young's modulus was defined by the secant modulus at 2.5 % elongation.

2.5 Calculation of Biobased content

The Biobased content[1] of the prototype coating agent was calculated by equation (1).

$$BC_{all} = \Sigma W_i \times BC_i \tag{1}$$

BC_{all} : Biobased content of coating

W_i : Weight fraction of raw material *i*

BC_i : Biobased content of raw material *i*

3. Result and Discussion

3.1 Investigation of oligomers using biomass raw materials

Oligomers for fiber coating should be designed with the optimal molecular structure depending on the application and required properties. Therefore, it is important to verify that oligomers can be synthesized using biomass raw materials in the same way as conventional petrochemical raw materials. In our previous research, we examined the feasibility of synthesizing oligomers using biomass raw materials and achieved partial success, while leaving room for further improvement. Regarding oligomers synthesized using conventional petrochemical raw materials, the results of past evaluations using biomass raw materials and newly added results using biomass raw materials will be explained in the following.

First, let us explain the development process of oligomers in secondary coating materials. Our previously developed biomass-derived oligomers showed no significant performance deficiencies compared to conventional petrochemical-based oligomers; however, their biomass content (BC) was relatively limited.

Therefore, we conducted further research to develop oligomers with higher biomass content, with the main purpose of increasing the overall proportion of biomass in the final formulation. Compared to the oligomers reported in our previous studies, we have successfully developed new oligomers with a 50% increase in biomass content, which represents an important advancement in the field of sustainable materials development.

Subsequently, Table 1 describes oligomers for primary coating (soft materials) contains the following information: representative names of each oligomer, flowability, color of the oligomers, and appearance color. When the flowability is too low, it will adversely affect the subsequent use of the oligomer. For coating materials, a transparent and colorless appearance is often preferred.

Regarding the oligomers utilized for primary coating materials, Table 1 presents a comparative analysis of various oligomers. The conventional petrochemical-based oligomer, designated as Oligomer PN, serves as the reference standard. Previous iterations of biomass-derived alternatives, identified as Oligomers PA and PB, exhibited significant limitations. Specifically, Oligomer PA demonstrated inadequate flowability (classified as Not Good), while Oligomer PB, despite possessing acceptable flow characteristics, presented an undesirable chromatic appearance. In our current investigation, we have successfully developed more than one novel biomass-derived oligomer, designated as Oligomer PC, which exhibits performance properties comparable to the conventional petrochemical-based reference material. Notably, these newly synthesized oligomers overcome the coloration issues or flowability challenges encountered in the previous generation development, representing a substantial advancement in sustainable material formulation for optical fiber coating applications.

Table.1 Oligomers for primary coating usage

Name	Flowability	Color
Oligomer PN	Good	Good
Oligomer PA	N.G.	Good
Oligomer PB	Good	N.G.
Oligomer PC	Good	Good

For Flowability: N.G. （Not Good） = Difficult to work with; Good = Easy to work with.For Color: N.G. (Not Good) = Colored or Non-transparent; Good = Clear and Transparent.

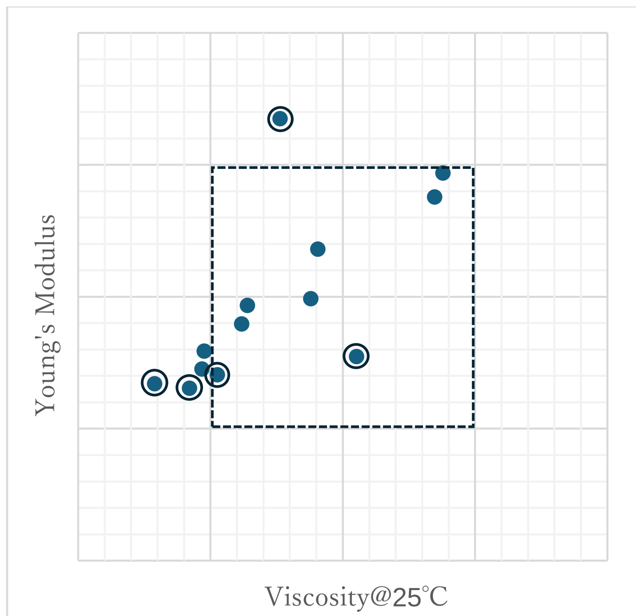
The above results indicate progress in the development of biomass-derived oligomers for optical fiber coatings. For secondary coatings, building on the initially limited biomass content of previously developed oligomers, we have further developed oligomers with higher biomass content ratios, with the highest biomass content reaching 1.5 times that of the previously developed product. For primary coatings, we have developed oligomers with similar levels of biomass content while improving upon previous limitations in flowability and coloration, developing easy-to-use oligomer PC that approaches the performance of conventional petrochemical products. These advancements offer new possibilities for sustainable development in complete optical fiber coating systems while maintaining the essential performance requirements of the materials.

3.2 Performance Mapping of Bio-based Coating Formulations

This section further elaborates on the performance characteristics of newly developed bio-based formulations. Through scatter plots of fundamental key properties—Young's modulus and viscosity—we demonstrate the performance ranges achievable with bio-based coating materials. These graphs present comparisons with previously developed products (represented by circled data points). The values for Young's modulus and viscosity performance are normalized using the center value of the required range, therefore units are not shown. The dashed rectangular boxes outline the requirements for Young's modulus and viscosity performance of current mainstream coating materials as a reference. Previously developed products are represented by solid circles with outer rings.

Figure 1 shows the experimental results for secondary coatings. We can observe that among previously evaluated formulations, only one falls within the practical range, indicating that adjusting viscosity and Young's modulus is not a simple task. However, in this study, we have added data for eight new formulations, with six of them positioned within the practical range and closer to the center of the target range. This newly added research data indicates that our newly developed biomass-containing formulations provide an expanded range of achievable Young's modulus and viscosity parameters within the practical range for secondary coatings.

Figure 1: Performance Mapping of Bio-based Secondary Coating Formulations

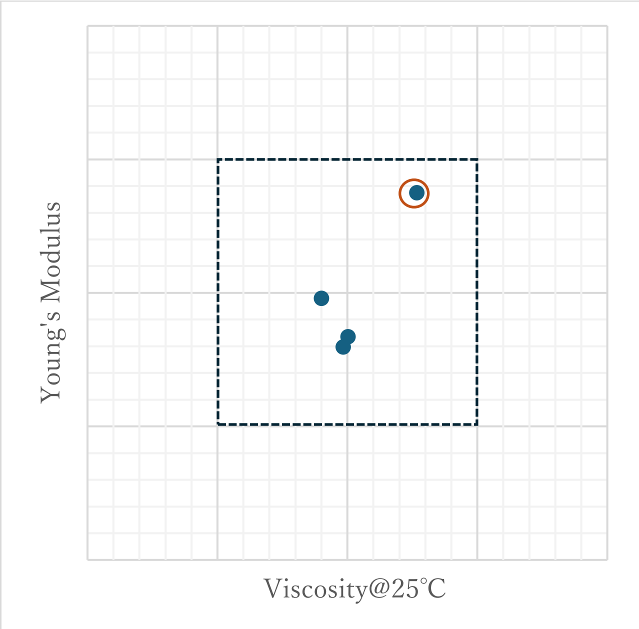


Normalized Young's modulus and viscosity values are presented using the center value of the required range as reference. Dashed rectangles indicate the performance requirements of current mainstream coating materials. Solid circles with rings represent previously developed products, while solid circles without rings represent formulations from this study.

In primary coating formulation research the greatest challenge lies in previous studies where primary coating formulations made with biomass oligomers having poor color characteristics exhibited a yellowish-brown appearance, failing to meet the requirement for transparent and colorless appearance. In this study, we successfully achieved the goal of formulating transparent and colorless biomass-based primary coating formulations using different raw materials.

Next, let's discuss the basic physical properties of these formulations - Young's modulus and viscosity. Figure 2 presents the experimental results of primary coatings near the practical target range of Young's modulus and viscosity. It can be observed that although the results from previous research fall within the practical range indicated by the dashed rectangle, both their Young's modulus and viscosity are positioned at the edge of the upper limits of the acceptable range. The three newly added formulations in this study not only fall within the target range but are also closer to the central position of the target range.

Figure 2: Performance Mapping of Bio-based Primary Coating Formulations

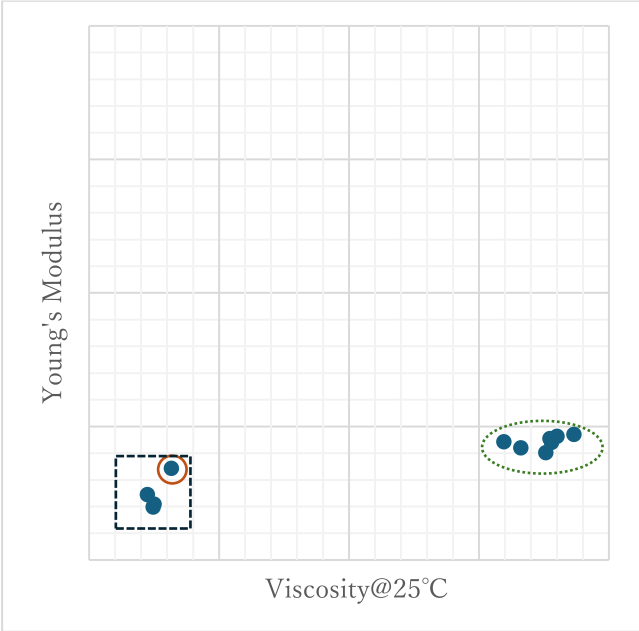


Normalized Young's modulus and viscosity values are presented using the center value of the required range as reference. Dashed rectangles indicate the performance requirements of current mainstream coating materials. Solid circles with rings represent previously developed products, while solid circles without rings represent formulations from this study.

Figure 3 presents a broad-range view of the Young's modulus and viscosity distribution of primary coating experimental results. Besides the dashed rectangle representing the practical range, a cluster of experimental data can be seen within the dashed elliptical area, which are formulations positioned outside the practical range due to excessive viscosity and slightly high Young's modulus.

Regarding the biomass content ratio of the primary coating formulations reported in this study, formulations within the target range have lower biomass content ratios, while those outside the target range have higher biomass content ratios. This indicates that to develop primary coating formulations with high biomass content, further adjustments are needed, especially reducing their viscosity, to enter the usable range, which will be the goal of our next research phase.

Figure 3: Performance Mapping of Bio-based Primary Coating Formulations with Broad-Range



Normalized Young's modulus and viscosity values are presented using the center value of the required range as reference. Dashed rectangles indicate the performance requirements of current mainstream coating materials. The dashed elliptical area highlights formulations with higher biomass content. Solid circles with rings represent previously developed products, while solid circles without rings represent formulations from this study.

4. Conclusion

This study explores the potential application of bio-based materials in optical fiber coating systems, addressing the important global trend toward carbon footprint reduction. Our research findings suggest that, with careful consideration of performance characteristics and rigorous formulation adjustments, biomass-derived oligomers may be applicable to optical fiber coating systems. This research focuses on solving unresolved issues from previous studies and confirms Young's modulus and viscosity within the practical performance range. For secondary coatings, we increased the oligomer biomass content to 1.5 times that of previously developed products. In formulation development, we report six formulations within the practical performance range, demonstrating the possibility to meet various application requirements through corresponding diverse Young's modulus and viscosity specifications. For primary coatings, we addressed key challenges in flowability and coloration from previous iterations, developing transparent and colorless formulations with higher biomass content. This study shows that these high biomass content formulations do not yet fully meet the requirements of the practical range; in the future, we will work toward achieving practical biomass formulations through rigorous formulation adjustments.

These advancements align perfectly with our strategic objective of incorporating biomass materials throughout the production process, thereby reducing the environmental impact of optical fiber manufacturing. Considering that coatings constitute 75% of the total fiber volume, the development of these bio-based alternatives has significant implications for achieving permanent emissions reductions and enhancing industry sustainability.

Future research will continue to optimize these bio-based formulations, particularly for primary coating materials with high biomass content, to further improve their performance within the practical range, making greater contributions to the sustainable development of the optical fiber communication industry.

5. References

[1] ISO 16620-1, 4

[2] Natsuki Hamada et al., "Investigation on application of biomass raw materials to optical fiber coating agent", 72rd IWCS (2023).

6. Pictures of Authors

Wanyu Liao

Kanagawa Research & Development Center (KRDC)

Japan Fine Coatings Co.,Ltd.

Kanagawa Science Park(KSP) Unit C-1225

3-2-1 , Sakado, Takatsu-ku, Kawasaki 213-0012 Japan

Wanyu Liao received his M.E. degree in Materials Process Engineering from Nagoya University of Engineering and joined Japan Fine Coatings Corp. in 2024. She has been engaged in research and development of polymeric materials including radiation curable materials for optical fiber coating.

Noriyasu Shinohara

Kanagawa Research & Development Center (KRDC)

Japan Fine Coatings Co.,Ltd.

Kanagawa Science Park(KSP) Unit C-1225

3-2-1 , Sakado, Takatsu-ku, Kawasaki 213-0012 Japan

Noriyasu Shinohara received his Ph.D. in organic chemistry from Tokyo Institute of Technology and joined JSR Corp. in 1996. In 2021, he moved to Japan Fine Coatings Corp. He has been engaged in research and development of polymeric materials including radiation curable materials for optical fiber coating.