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The study of UV foaming technology for ABF bundle

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Abstract

To carry fiber from one located to another in ABF (Air Blown Fiber) bundle installation, the fiber bundle needs to have special aerodynamic properties and light weight for long blown-distance. The thermal extrusion-foaming technology is commonly used to make lightweight and bumpy surfaced sheath for low friction in conventional ABF bundle production.

In this study, the photochemical (Ultra Violet) reaction is employed to foam gas bubbles trapped in the coating film for optical fiber bundle. The gas bubbles trapped in the film lower the density of the coating significantly down to one half of that of the solid film. Spontaneous UV curing of the coated resin and UV foaming of the gas bubbles in the cured film will not only lower the density of the bundle and but also increase the line speed in ABF bundle production at least to ten times compared to that of regular thermal extrusion and foaming system.

Keywords

ABF, air blown fiber, polymer sheath, optical fiber coating, UV cure, foaming, low friction, photo cure, photodecomposition, radical curing.

1. Introduction

Optical fiber cables are installed in much the same way as copper wire cables. The fiber cable is pulled into place through ducts and conduits using a rope attached to a cable end. The Cables experience very high tensile loadings during such installation, and consequently optical fiber cables need very considerable reinforcements to prevent the optical fibers from being damaged. These requirements increase the size, weight, cost of optical fiber cables and limitation in installation length. Air blown fiber system is an alternative approach to optical fiber installations method. It is known to blow optical fiber cables into ducts in order to install long, continuous lengths of optical fiber cables over long distance, such as to install optical fiber cables in so-called sub-ducts in kilometer lengths. In this method the fibers are installed along a previously installed duct using fluid drag of a gaseous medium, which passes through the duct in the desired direction of advance. This method uses distributed viscous drag forces to install a cable unit that is supported on a cushion of air.[1-2]

The fiber bundle for ABF application should be designed to meet various physical requirements for long distance installation. The lightweight and low surface friction between the bundle and the duct are main concerns in optical fiber bundle design. The lightweight and low friction design will give longer installation distance and less tensile loading in optical fibers. In typically design, optical ribbon units consist of plurality of conventionally coated fibers are held together in lightweight polymer sheath which contain foamed bubbles to reduce weight and surface friction.

Commonly, foamed skin is made by thermal cure coating system. The coating consists of thermal cure polymer resins and heat blowing agents. By heat extrusion process, the polymer is cured to provide physical strength as sheath and the blowing agent is decomposed to foam gas bubbles. This extrusion and heat foaming processes limit the production speed to one tenth of conventional fiber optic industries standard.

UV cure technology has been successfully implemented to optical fiber coating and cabling processes for the high-speed production up to 2,500 meter/minute. By combining this UV cure polymer coating and UV decomposition technology, UV foaming process has been developed.[1-5] In this paper, several UV curable compositions (EFIRON®) including photo-reactive oligomers, monomers and photo-decomposition reagents, which fit for use in UV curing system as blowing agent, are studied for ABF application. This new development coating resin (EFIRON®) can be new material for polymer sheath to make lightweight air blown fiber bundle.

2. Basic principle

2.1 Photodecomposition & Radical Quenching

Most conventional thermal foaming processes can utilize chemical blowing agents (CBAs), also known as foaming agents. CBAs are added to the polymers during thermal processing to form minute gas cells throughout the film. The gas is liberated by chemical changes in the CBA. The foamed cellular structure reduces polymer film density, saves in materials costs, improves thermal insulating properties and increases the strength-to-weight ratio. The liberation of gas when heating chemical foaming agents occurs through series chemical reactions or decompositions. Different chemical foaming agents have different decomposition temperatures depending on their chemical structures. The most used CBA for medium temperature polymer processing (325~430 °F) is azodicarbonamide. The some of blowing agents are decomposed into gaseous products when subjected to sufficient conditions, for example by raising temperature or even by sufficient photo energy radiation. Generally, materials which have functional groups such as photosensitive or chromospheres in their main backbone or photo-resist reagent in their compounds can be reacted and de-composed by photo-energy. [3-4]

–N= N-, - CH=N-, -CH=CH-, -C≡C-, -NH=NH-, -S-, -NH-, -O-, >C=O are typical photo sensitive functional groups, which absorb photo-energy easily. Therefore molecules including those functional groups can be decomposed by photo-energy and possibly be used as photo-induced blowing agents. To be used as a blowing agent, the molecule should be easily decomposed by UV radiation and generates gas like nitrogen or carbon dioxide. As one of examples, the molecules contain diazo group, which absorb strongly UV energy around 200 ~ 300nm wavelength range, decompose and generate nitrogen gas. In Figure 1, the chemical reaction route illustrates the generation of nitrogen gas by azo-group and some side-reactions. [5-7]

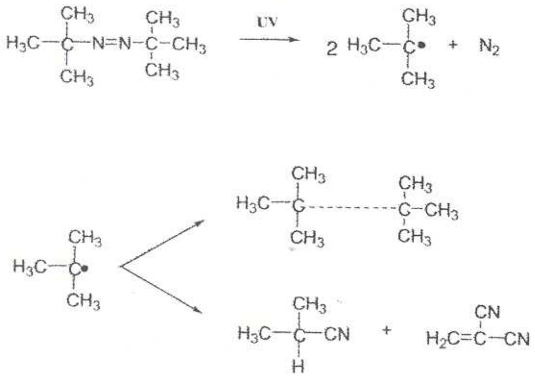

Fig 1. Azo compound decomposition by UV energy

Nitrogen gas generation synchronize with ultra violet cure of polymer compounds. Therefore the gas is trapped in cured solid coating film as like foam.

Unfortunately, azo blowing agents, which can be used in photo-induced foaming application, decompose into products, which adversely affect the photo-induced polymerization. For example, the decomposition products, especially radicals, undesirably react with monomers, oligomers and even with cured polymers, lowering the molecular weight, and causing brittleness in the final cured polymeric film. It would be desirable to have azo blowing agents, and/or a method of UV curable foaming compositions wherein the agents would be versatile, and would have degradation products which would not react with the final polymeric film. This kind of azo compound can be prepared by various known methods like reacting a diazonium ion with an organometallic compound, or contacting an isocynate-substituted aromatic compound with a tertiary alkyl- primary amine compound; and then oxidizing urea compound.

Photo-intensifiers and metal complexes behave as catalyst when be added in photosensitive compounds. Photo-intensifiers contain aromatic ketone groups, for example benzophenone, acetophenone and acetoquinone take hydrogen molecules from photosensitive compounds and help the decomposition process by lowering decomposition energy.

2.2 UV curing system and formulation

Radiation Curing is the technology of utilizing short wavelength ultraviolet light (UV), or high-energy electrons from electron beam (EB) sources. UV curable coatings are formulated using selective materials that react to UV energy forms to yield very specific performance properties. UV cure process causes liquid coating to change into solid film virtually instantly. Curing is very fast and cool in relative terms, which allows applications to high-speed production and to heat sensitive substrates. Once cross-linked by UV curing, properly cured products exhibit both highly physical and chemical resistant properties. [8-10]

A radiation curable formulation consists of the flowing components;

1. Prepolymers, urethane based oligomers
2. Reactive diluents, monomer contain acrylates
3. Additives for leveling and storage stability
4. Photo-initiators (PI) for UV curing process

Obviously, for a UV curable formulation, it is necessary for a UV photo-initiating system to be present. This applies to both free radical and cationic curable systems. [11-13] Much of the selection of a photo initiator is connected with its effect on cure rate and degree of cure, thus frequent reference will be made to the assessment cure. Urethane based oligomers and special monomers should be selected to overcome the brittleness due to the azo side reaction and to give enough toughness so that the cured film protect the optical fiber from being damaged during the ABF installation.

3. Experiment and Result

The same amount of photoinitiator (PI), azo blowing agent and metal complex catalyst are mixed in a solvent and the mixture is tested to illustrate the effect of the catalyst to UV absorption of PI and blowing agent (BA).

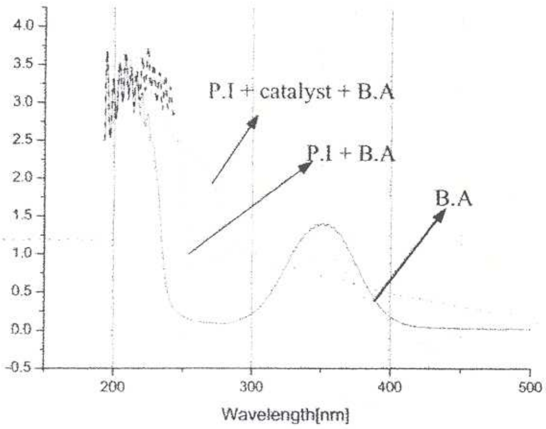

Fig.2 UV absorption of azo compounds

Figure 2 shows the ultra violet absorption of various mixtures of azo compound, photo initiator and metal complex catalyst. The total area under the graph represents the total absorption of photo-energy. The mixture of photo-initiator and photo-induced blowing agent shows higher absorbance due to the absorption of the blowing agent. The addition of metal complex catalyst into the previous mixture even enhances the absorption of UV energy. By implementing this UV-induced generation of gas and radical system into the UV cure coating formulation, the foam like film can be achieved by the conventional UV curing process

To find out the effect of azo compounds as blowing agent in UV curing compounds, diacrylate oligomers (Mw 4,500 ~ 5,000) and mono, di, multi functional acrylate monomers and photo-initiation compounds are mixed with photo-induced blowing agents and organometallic catalyst. The urethane diacrylate oligomers included polycarbonate groups are applied to these experimental compounds to increase the toughness and hardness of the cured film. Monomers having low acrylate contents are selected to decrease viscosity of coating solution and curing shrinkage. These monomers enhance the flexibility of UV cured film. Hydroxyl alkylphenone type photo-initiator is cooperated for D-bulb curing system.

Various UV curable coating formulations containing different amount of photo-induced blowing system are prepared as Table 1 below.

Table 1. UV curable formulation (wt %)

	A	B	C	D
Oligomer	73.3	72.8	72.3	71.8
Monomer	25			
Photoinitiator	1.0			
Blowing agent	0.5	1.0	1.5	2.0
Catalyst	0.2	0.2	0.2	0.2

Each coating materials A/B/C/D, as shown in Table 1, is cured with different UV power conditions from 300 mJ/cm^2, 100 mJ/cm^2, 70 mJ/cm^2 and to 50 mJ/cm^2. For UV curing, Fusion 600I/VPS model equipped with D 600 Watt bulb lamps is used to make specimens with variation of UV radiation power. The density of each cured film is measured to analyze the effect of radiation power and dose of the blowing agent. The test results are illustrated in Figure 3.

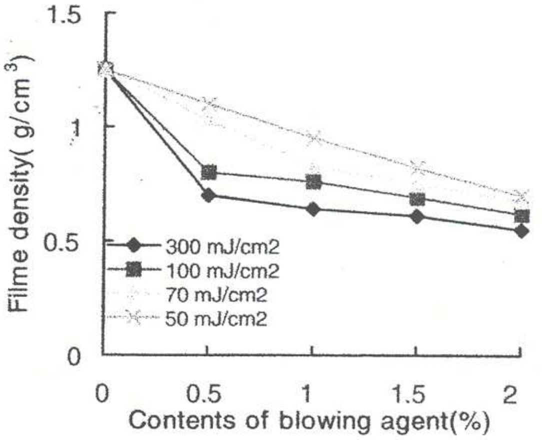

Fig. 3 Density of film with four different UV power

The density of the cured film decreases proportionally with increasing blowing agent content. But there is a limitation showing the saturation of blowing agent effect. The higher power level of radiation enhances the activation of the blowing agent even more, but there is also saturation point. This result implies the balance of doze of blowing agent and UV power level is critical to achieve the strong UV cured film with lower density and good toughness

Figure from 4.1 to 4.4 are the microscope pictures of UV cured film surface of the formulation D with various UV power levels. This sequenced pictures shows increasing in number of bubbles trapped in the cured film when the UV power level is increased.

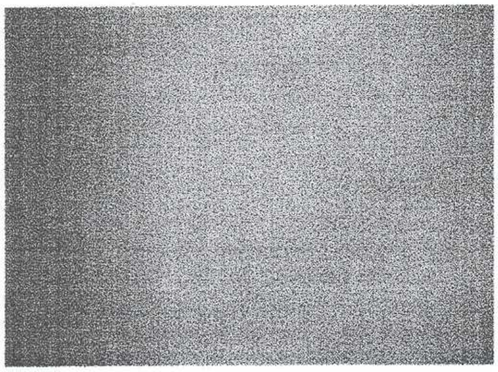

Fig. 4.1 Standard Film without the blowing agent

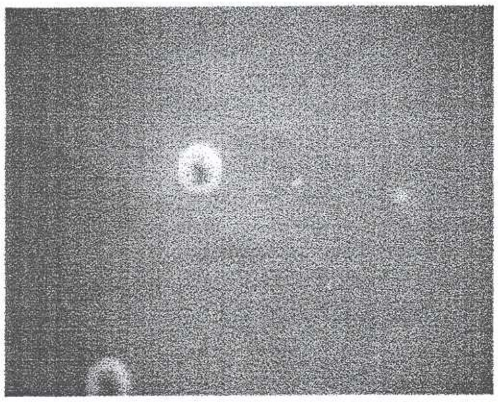

Fig. 4.2 Sample D with UV dose of 70 mJ/cm^2

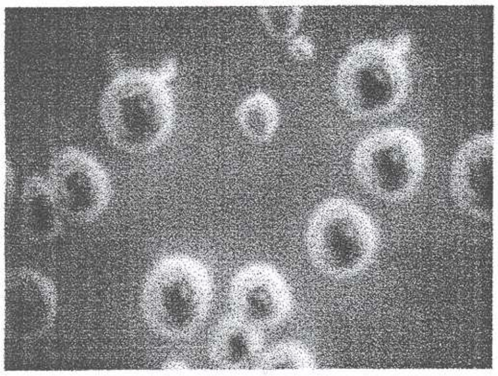

Fig. 4.3 Sample D with UV dose 100 mJ/cm^2

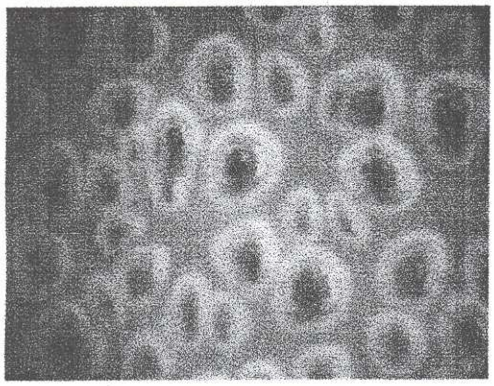

Fig. 4.4 Sample D with UV dose 300mJ/cm^2

Figure 5.1 and 5.2 are the microscope picture of the cross sections of the cured film without the blowing agent and the cured film with the blowing agent at 300 mJ/cm^2 power level (Figure 4.4). The thickness of the Figure 5.2 is doubled compared to that of Figure 5.1. This increase in volume due to the gas trapped in the film lower the density of the film to half.

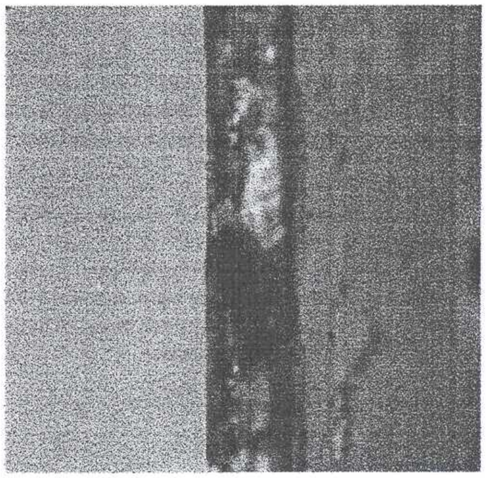

Fig. 5.1 The cross section of film (Fig 4.1)

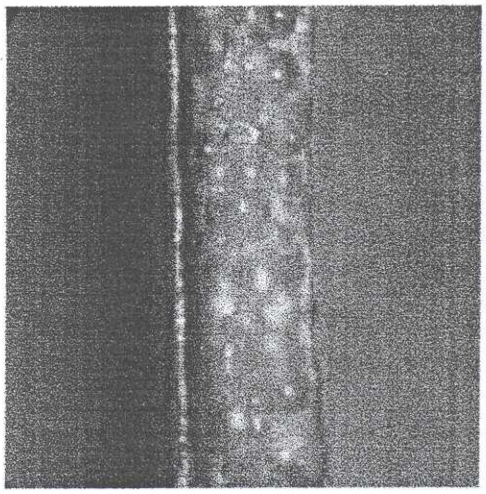

Fig. 5.2. The cross section of Fig. 4.4

Surface friction coefficient of the UV cured foam film is measured by UTM (Universal Testing Machine; Instron). The film is folded and 500g of weight is loaded over the folded film; and then the maximum loading is measured to move the upper film. Typically, the friction coefficient of matrix coating for optical fiber bundle is in the range of 0.6 ~ 1.0 kg_f. The friction coefficient of the UV cured form film with 300mJ/cm^2 is measured to be 0.2kg_f, which is lowered by 1/3 ~ 1/5 compared to that of regular UV cured film. This low friction surface created by the UV induced bubbles lower the tensile loading of optical fiber in the ABF installation.

4. Conclusion

In this experiment, with implementation of UV induced blowing agent system into conventional UV curable optical fiber coating, the low density and low friction surface film can be achieved from UV cure process. The density of foam film is proportional to blowing reagent content and ultra violet energy with limitation of saturation point. Some of formulations show the decrease of density by 40% with only 100mJ/cm^2 UV power. Typically, UV systems in fiber bundle and optical fiber coating production lines are operated over the 400 mJ/cm^2 power level. Under these conditions, the density of foam film can be reached easily down to 0.50 g/cm^3. Therefore, low-density polymer sheath for air blown fiber bundle can be made in conventional UV curing system of optical fiber coating industries using this new formulation. This new UV curable coating material trade-named EFIRON® makes it possible to produce ABF optical bundle faster and cheaper than conventional thermal process.

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