Development of a 2.5 μm Polyethylene Film for the High Altitude Balloon

Eiichi MIZUTA¹⁾, Daisuke AKITA¹⁾, Hideyuki FUKU¹⁾, Issei IJIMA¹⁾, Naoki IZUTSU¹⁾, Yoichi KATO¹⁾, Jiro KAWADA¹⁾, Yukihiko MATSUZAKA¹⁾, Michiyoshi NAMIKI¹⁾, Naoki NONAKA¹⁾, Shigeo OHTA¹⁾, Yoshitaka SAITO¹⁾, Motoharu SEO¹⁾, Atsushi TAKADA¹⁾, Keisuke TAMURA¹⁾, Michihiko TORIUMI¹⁾, Kazuhiko YAMADA¹⁾, Takamasa YAMAGAMI¹⁾, Tetsuya YOSHIDA¹⁾, Kouji ICHIMURA²⁾, and Tsutomu KOBAYASHI³⁾

¹⁾Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (ISAS/JAXA), Kanagawa, Japan

²⁾UBE-MARUZEN POLYETHYLENE Co., Ltd., Tokyo, Japan

³⁾SHIBATAYA KAKOHSI Co., Ltd., Niigata, Japan

(Received May 2nd, 2008)

We have developed ultra thin polyethylene film for the high altitude balloon which can float in the mesosphere. It is required that the development of thin and strong polyethylene films to reduce the weight of balloons themselves. But it was difficult to manufacture the ultra thin film under 2.8 μm in thickness by a conventional film manufacturing machine. In 2005, we developed a new machine and succeeded in manufacturing 2.5- μm -thick film. We measured its strain-stress properties at low temperature and confirmed that the film is suitable for balloons which float in the mesosphere.

Key Words: Mesosphere, High Altitude Balloon, Polyethylene Film

1. Introduction

In these years, scientific balloons have attracted considerable attention for their high cost-efficiency and flexibility of the experiment. Scientific balloons can reach mesosphere and also stay at the altitude for a long time. One can observe the atmospheric constituents including ozone and their distribution at the mesosphere¹⁻⁴⁾.

We have developed high altitude balloon using ultra thin polyethylene films. To float at high altitude, there are two methods. One is utilizing large balloon, and the other is utilizing light balloon. Fig. 1 shows the relation between the volume of a balloon and its ceiling altitude for various films, assuming the gondola weight of 10 kg and the flight train weight of 1 kg. Utilizing light balloon is much effective to reach the higher altitude; i.e. though a 10,000 m^3 -balloon with a 20 μm film float only up to 35 km, a 2.8 μm film with the same volume can reach at 45 km. Thus, we improved the thickness of balloon films by changing the density of the resin and developing the manufacturing machine as shown in Fig. 2. In 1997, we started to develop thin polyethylene films with resins using a metallocene as a catalyst. In 2002, a 60,000 m^3 balloon with 3.4 μm thin films (Fig. 3) achieved the world record of 53.0 km as the highest altitude of a unmanned balloon⁵⁾. In 2003, we succeeded to manufacture a 2.8 μm films⁶⁾. Since it was difficult to manufacture thinner films by the conventional machine, we developed a improved machine to manufacture this time. In this paper, after introducing the new machine, results of tensile test of its products will be described and their availability will be discussed.

Fig. 1. Relation between the volume of a balloon and its ceiling altitude.

Fig. 2. History of the development of the ultra thin polyethylene film for high altitude balloons.

Fig. 3. Launching of the balloon reaching the highest altitude of 53.0 km in 2002.

2. Deposition System

2.1. Film Manufacturing Method

Fig. 4 shows the procedure of a conventional manufacturing machine for polyethylene films using the inflation method. The machine consists of a hopper, a push bench, a screen pack, a die, an air ring, a fin, a pinch roll, and a take-up unit. First, the resin is cast into the hopper and mixed well by the screw and heated. Next, contaminations of the resin are removed by the filter (screen pack) and the resin is pushed into the die. The melt resin is pushed into the air through a circular slit. Then, the resin is inflated as a tube by air from the central hole in the die and cooled by the air ring. Finally, the film is taken up by the take-up roller removing the air using the fin and the pinch roll. The film thickness is determined by the combination of the injection and the

winding speed. A direction to pull a film is called Machine Direction (MD), and perpendicular direction to the MD is called Transverse Direction (TD).

2.2. The New System

Based on the conventional manufacturing machine, we developed a new machine for thin balloon films. We improved the following points; (1) fixing the driving machine directly on the ground, (2) adopting a screw which can mix the resin uniformly, (3) controlling the cooling temperature appropriately to improve the stability of the film by using the high air ring, and (4) using a hard and smooth rollers for pinch roll. The take-up roller improved the streaking and wrinkles of the film. As a result, it becomes possible to stand up and inflate the film stably in the air ring and to take it up by a uniform tension. Using this machine, we could manufacture films of 2.8 μm and 2.5 μm in thicknesses with a width of 280 cm.

We searched for defects such as a fish-eye and a contamination in the films. We could only found one deficit per 18 m and confirmed their high quality (Fig. 5).

Fig. 5. Sample of a fish-eye and a contamination in the film.

Fig. 4. Film manufacturing machine using the inflation method.

3. Tensile Test

We performed tensile tests of new films. Fig. 6 shows the tensile test machine (201B made by INTSCO) and the shape of the sample film. The sample has dumbbell shape which has a central part of $W5 \times L25$ mm with the top and the bottom part to be held to pull the sample. The temperature conditions were set to 25 °C and -40 °C, and the pull speed was 100 mm/min. Fig. 7 shows results of the 2.8 μm film, and Table 1 summarizes the results. These results indicate that this film has sufficient ultimate strength and elongation in both MD and TD direction at 25 °C. The ultimate strength and elongation of new film are similar those of the film manufactured by the conventional machine. Fig. 8 shows the results of the 2.5 μm film as summarizing in Table 1. The properties of the 2.5 μm film both MD and TD were also similar to those of the 2.8 μm . Fig. 9 shows the summary of the results.

Fig. 6. Tensile test machine and the shape of the film sample.

Fig. 7. Strain-stress curves of the 2.8 μm film.

Fig. 8. Strain-stress curves of the 2.5 μm film.

Table 1. Summary of the tensile test.

Thickness	Machine type	Temperature	MD		TD	
			Ultimate strength [kg/cm ²]	Ultimate elongation [%]	Ultimate strength [kg/cm ²]	Ultimate elongation [%]
2.8 μm	New	25 °C	335 ± 60	480 ± 45	275 ± 45	670 ± 50
		−40 °C	485 ± 120	350 ± 30	297 ± 80	180 ± 155
2.5 μm		25 °C	370 ± 60	515 ± 25	255 ± 45	610 ± 60
		−40 °C	455 ± 50	285 ± 40	305 ± 30	235 ± 125
2.8 μm	Conventional	25 °C	340 ± 20	610 ± 20	250 ± 20	790 ± 20
		−40 °C	440 ± 10	400 ± 10	440 ± 30	460 ± 70

Fig. 9. Ultimate strength and ultimate elongation vs. temperature.

4. Discussion

It is important to compare the film strength and the stress of balloon films. Assuming that the balloon shape is symmetrical to a vertical axis, and has uniform weight distribution, we can calculate the maximum stress per unit length as follows,

$$\sigma_{\max} = [\min(r(s), R_m(s)) \Delta p(s) / t(s)]_{\max} \quad (1)$$

where, s denotes the length along the balloon meridian line from the base of the balloon, and, r , R_m , Δp , and t indicate the radius of balloon, meridian radius of curvature, pressure difference, and effective envelop thickness, respectively (Fig. 10). All of them are functions of s . The stress becomes maximum on the ground level. Under the balloon volume is 60,000 m³, the film thickness is 2.5 μm and payload weight is 6.7 kg, the maximum film stress is 170 kg/cm². This value is below the ultimate strength of the 2.5 μm film, so we confirmed that these films can use the high altitude balloons.

5. Conclusion

We developed a new deposition system for ultra thin balloon films. We could manufacture the 2.8 μm and 2.5 μm films. We performed the tensile test of those films and found that these films had enough ultimate strength and ultimate elongation at 25 °C and -40 °C, and we

Fig. 10. Surface of a balloon.

confirmed that the film can be used for the high altitude balloons. We are going to develop the highest altitude balloon using these films.

Acknowledgments

We would like to express our sincere gratitude to the members of SHIBATAYA KAKOHSI Co., Ltd. for their continuous support for manufacturing balloon films.

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