

Cavitation erosion of low-density polyethylene coatings for pipe liners

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Abstract. The relationship between mechanical properties and the erosion rate was examined for chloroprene rubber and a number of polyethylene materials produced by different methods. As electric power plants are in operation over long periods of time, the effect of aging was also examined by testing material intended for use in pipes in electric power plants. Cavitation erosion tests were carried out by using a flowing apparatus as specified in the American Society for Testing Materials G134-95 standard. A flow velocity of 150 m/s and a test time of 24hours, were the experimental conditions used for a cavitating liquid jet test on polyethylene. The maximum depth of erosion rate (MaxDER) of polyethylene was found to decrease with the increase in hardness. Among all the tested materials, the relatively high molecular weight polyethylene with low density (m-LLDPE-H), showed the best resistance to cavitation erosion in terms of MaxDER. The effect of aging on the erosion rate of polyethylene was limited.

1. Introduction

Resin lining is widely used as an anti-corrosion method of steel pipes for tap water and water conditioning in chemical plants and electric power plants. Since there are many valves for piping systems, and cavitation sometimes occurs near valves, it is necessary to consider not only the corrosion resistance but also the erosion resistance to cavitation. Barletta and Ball [1] carried out cavitation erosion tests for many kinds of polymeric materials and found their erosion resistances. Kobayashi et al. [2] carried out erosion tests of lined pipes with epoxy resin, tar epoxy, polyester, polyethylene and neoprene rubber using a butterfly valve, and found that chloroprene rubber has the best erosion resistance. The second best erosion resistant material was polyethylene, showing the loss of luster on bright surface without material removal. The authors [3] carried out the cavitation erosion tests for epoxy resin, polypropylene, high-density polyethylene and polyamide 66. It was found that the cavitation erosion resistance can be evaluated in terms of bubble collapse impact energy and the strain energy obtained from fatigue strength. Recently, Deplancke et al. [4] found that ultra-high molecular weight polyethylene showed a high cavitation erosion resistance. But this material is difficult to fabricate components. In general, the mechanical properties of plastics can vary with the catalyst, material density, and the mixture with elastomer. However, little cavitation erosion research has been done from this viewpoint.



In this study, nine kinds of polyethylene and one chloroprene rubber were fabricated to carry out the cavitation erosion tests using a cavitating liquid jet apparatus. The erosion rate was evaluated in terms of mechanical properties of the materials. Many pipes in electric power plants are expected to be used for 60 years. The specimens after aging treatment were used for the cavitation erosion test. The effect of aging on the erosion rate was examined.

Table 1. Physical and mechanical properties of polyethylene and chloroprene rubber.

Material	Density (g/cm ³)	Melting point (°C)	Elonga- tion (%)	100% modulus (MPa)	Tensile strength (MPa)	Durometer hardness HDD
Z-LLDPE	0.926	120	560	9.5	13	55
LDPE	0.921	109	510	-	14	53
m-LLDPE	0.933	122	560	10.3	14	59
E-LLDPE-10%	0.930	123	720	-	21	55
E-LLDPE-15%	0.929	123	560	9.6	14	54
E-LLDPE-30%	0.924	123	640	9.0	18	47
CL-LLDPE-1	-	-	520	11.4	16	59
CL-LLDPE-2	-	-	580	11.5	20	60
m-LLDPE-H	0.940	126	880	-	24	62
Chloroprene rubber (CR)	-	-	460	2.5	12	74 (HAD)

*100% modulus indicates the stress at 100% strain.

2. Experimental procedure and materials

Cavitation erosion test were carried out by using the vibratory apparatus which is specified in the American Society for Testing Materials (ASTM) G32 standard. However, no erosion occurred for the polyethylene used currently. Therefore, the cavitation erosion tests were carried out using the cavitating liquid jet apparatus specified in ASTM G134 standard. Jet velocity V and cavitation number σ were calculated based on ASTM G134 standard.

$$V = \sqrt{\frac{2}{\rho}(p_u - p_d)} \quad (1) \quad \sigma = \frac{p_d - p_v}{p_u - p_d} \quad (2)$$

where ρ is a liquid density, p_u is upstream pressure, p_d is downstream pressure and p_v is vapor pressure. Cavitation number σ was set at 0.025, as defined by ASTM G134-95 for all tests, and the flow velocity was determined by adjusting the upstream and downstream pressures.

The physical and mechanical properties are listed in Table 1 for nine kinds of polyethylene and a chloroprene rubber. Z-LLDPE is a linear-chain low-density polyethylene, polymerized by Ziegler catalyst. LDPE is a low-density polyethylene polymerized by a high pressure method. m-LLDPE a linear-chain low-density polyethylene polymerized by metallocene catalyst m-LLDPE (reference resin). Polyethylene E-LLDPE-10%, 15% and 30%, with various additions of elastomer, were also among the test materials. Polyethylene CL-LLDPE-1 and -2, with the different molecular weights, was also used. Also included was m-LLDPE-H, which is the same as m-LLDPE but with increased density. Chloroprene rubber was also used. 100% modulus is the stress at 100% strain. Therefore, the high value of 100% modulus means that the material is hard to deform. Hattori et al. [3] reported that bubble collapse impact loads decrease on the low value of Young's modulus materials. The polyethylene with addition of elastomer was expected to improve the erosion resistance because of low 100% modulus. On the other hand, it is reported that high hardness material is erosion resistant. The high molecular weight materials were expected to improve the erosion resistance.

3. Experimental results and discussion

3.1. Cavitation erosion of polyethylene and chloroprene rubber

A cavitation erosion test of E-LLDPE-30% was carried out at a velocity of 184 m/s (upstream absolute pressure $p_u=17.4$ MPa and downstream absolute pressure $p_d=0.44$ MPa) for two hours. Heat melting

was observed. Therefore it became necessary to find the suitable flow velocity for the cavitation erosion test of polyethylene without heat melting. Cavitation tests of Z-LLDPE were carried out at a constant cavitation number of 0.025 as a function of flow velocity. The flow velocity of 150 m/s (upstream absolute pressure $p_u=14.5\text{MPa}$ and downstream absolute pressure $p_d=0.29\text{MPa}$) and cavitation number 0.025 were found to be suitable for the polyethylene tests when using the cavitating liquid jet apparatus, because no heat melting occurs and the erosion proceed gradually.

After 24 hours, the eroded surface of the specimen was observed three dimensionally by digital microscopy. Figure 1 shows the surface profile through the maximum depth of erosion (MaxDE). This, plus the piling up height and the width are shown in the figure. MaxDER is the MaxDE divided by the exposure time of 24 hours.

Figure 2 shows the relationship between the 100% modulus of polyethylene and MaxDER. The dashed line is the MaxDER of austenitic stainless steel SUS304. Since the MaxDE of SUS304 was 370 μm after 24 hours, the MaxDER is $15\mu\text{m/h}$, which is shown by a horizontal line. The MaxDER of Z-LLDPE and E-LLDPE-30% is higher than that of SUS304 and the rest of the polyethylene has superior erosion resistance. Hattori et al. [3] reported that the erosion resistance of plastics is high because the bubble collapse impact load becomes small due to the low acoustic impedance. Since the material density of all polyethylene used in this study is almost the same, the 100% modulus is equivalent to the acoustic impedance ρc , because $\rho c = \sqrt{E\rho}$ (ρ is material density, c is sound velocity and E is Young's modulus). E is proportional to the 100% modulus. The MaxDER was expected to enlarge due to the increase in 100% modulus, but the result in this study shows an opposite trend. This is because the range of 100% modulus in this study is narrow and because the mechanical property was changed, thereby overlapping the 100% modulus.

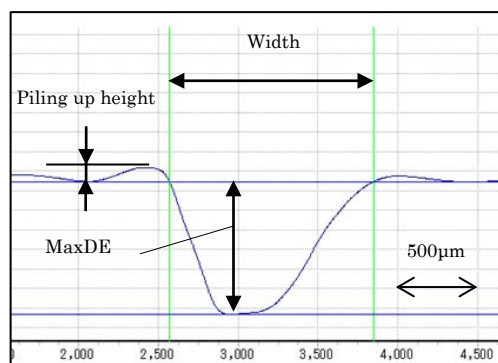


Figure 1. Surface profile (Z-LLDPE, 24h).

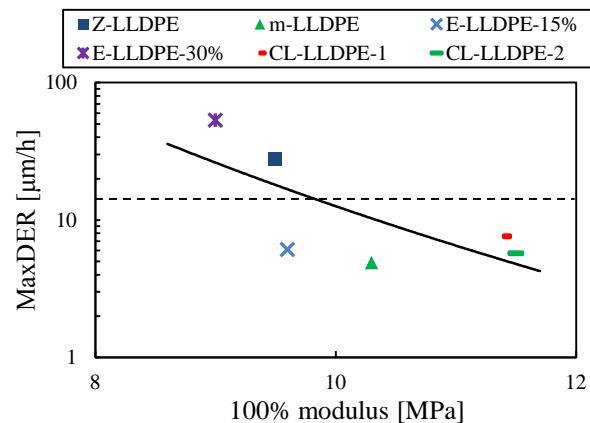


Figure 2. Relationship between 100% modulus and MaxDER with a trend curve.

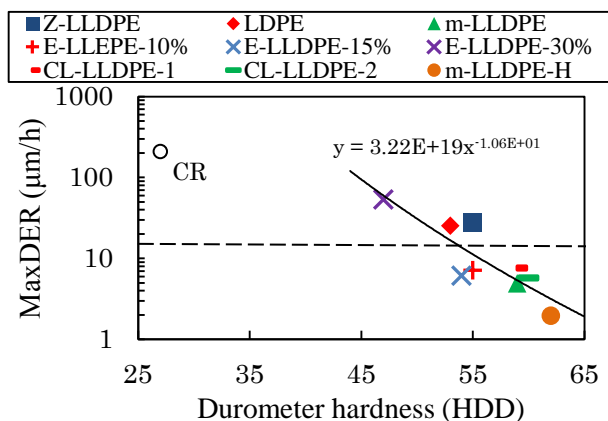


Figure 3. Relationship between durometer hardness and MaxDER.

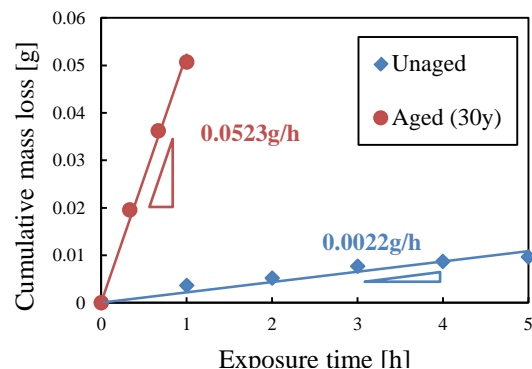


Figure 4. Cumulative mass loss-time curves for chloroprene rubber.

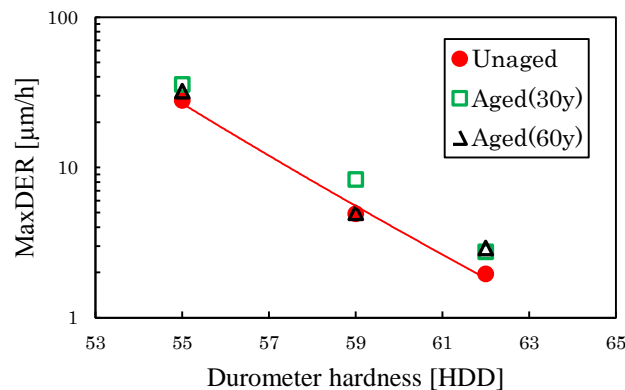


Figure 5. Relationship between durometer hardness and MaxDER for aged specimen.

Figure 3 shows the relationship between MaxDER and the durometer hardness of polyethylene and a chloroprene rubber (CR). The MaxDER of polyethylene decreases with durometer hardness. Thus, the erosion resistance of polyethylene is improved by an increase in hardness, as is the case with regular metals.

3.2 .Cavitation erosion of aged polyethylene and chloroprene rubber

Aged materials were made by the accelerated oxidation method which was obtained by a long immersion of lining material in tap water at 85°C. The average temperature of seawater in the real pipes is 20°C.

Figure 4 shows the cumulative mass loss-time curves for unaged and 30-year-aged specimen of chloroprene rubber. The mass loss rate is defined as the slope of the cumulative mass loss-time curves. The mass loss rate of the 30-year-aged specimen is about 24 times higher than that of the unaged specimen. Thus, the erosion resistance of chloroprene rubber decreases with aging.

Figure 5 shows the relationship between durometer hardness and the MaxDER for unaged and aged polyethylene. The hardness of aged polyethylene is almost the same as that of unaged polyethylene. The increasing ratio of the MaxDER for aged polyethylene is at most twice as high as with the unaged polyethylene. Thus, it was concluded that the effect of aging on the erosion rate is very small.

4. Conclusions

In this study, nine kinds of polyethylene, and a chloroprene rubber, were fabricated and used for cavitation erosion tests using a cavitating liquid jet apparatus. The erosion rate was evaluated in terms of the mechanical properties of the materials.

- (1) A flow velocity of 150 m/s (upstream absolute pressure $p_u=14.5\text{MPa}$ and downstream absolute pressure $p_d=0.29\text{MPa}$) and cavitation number 0.025, were suitable for the erosion tests of the polyethylene using the cavitating liquid jet apparatus.
- (2) The MaxDER does not decrease with decreased 100% modulus. The MaxDER decreases with durometer hardness. Thus, the erosion resistance of polyethylene is improved by the increase in hardness, as is the case with regular metals.
- (3) The erosion resistance of chloroprene rubber decreases with aging, because the hardness of the chloroprene was reduced when the material was aged. The increasing ratio of the MaxDER for aged polyethylene was at most twice as high as that for the unaged polyethylene. Thus, the effect of aging on the erosion rate is very small. It was thought that the oxidation rate of polyethylene was low as compared with that of chloroprene rubber.

References

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