In this paper we describe an experimental study on the characteristics at low temperature of welded low density polyethylene. That is to say, we report the results of some measurements on the mechanical properties, fractured surfaces, x-ray diffraction patterns and electron spin resonance spectra, and discuss them in this paper.\textsuperscript{11-13}

**INTRODUCTION**

This study is to clarify the low temperature characteristics of weld comparing with those of base material, and change in mechanical properties from room temperature down to the neighborhood of $-70^\circ$C and fracture in low temperature experiment in microscopic view point are discussed. Notch and load velocity effects on the brittle fracture tendency are also discussed. Testing materials were low density polyethylene board of 2mm. in thickness, and tests were carried out in low temperature of methyl alcohol and dry ice. A heat plate welding apparatus, with which specimens can be secured under fixed contact force, was made in order to carry out the experiment of welding.

**EXPERIMENTAL RESULTS AND CONSIDERATION**

Fig. 1 shows the result of experiment under different welding conditions, from which it is noted that welding joint efficiency of 100% could be attained at the welding temperature of 150$^\circ$C. Table 1 shows the summary of welding conditions obtained through preliminary experiment, and the figures appeared in this Table were used in subsequent series of experiments. Fig. 2 is the stress-strain curves of the base material at each low temperature, and yielding points are shown with "O". Fig. 3 is the stress-strain curves of the welded material. In comparing these Figures, some difference are observed in elongation beyond the yielding points, although both materials are alike in low temperature characteristics. Fig.
Fig. 1 Result of experiment under different welding conditions.

Table 1 Used welding condition.

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<table>
<thead>
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<tbody>
<tr>
<td>Cross-sectional area</td>
<td>30 mm²</td>
</tr>
<tr>
<td>Control switch of welder</td>
<td>Low</td>
</tr>
<tr>
<td>Preheating temperature</td>
<td>150±4°C</td>
</tr>
<tr>
<td>Preheating pressure</td>
<td>33 g/mm²</td>
</tr>
<tr>
<td>Preheating time</td>
<td>15 sec</td>
</tr>
<tr>
<td>Welding pressure</td>
<td>28 g/mm²</td>
</tr>
<tr>
<td>Welding time</td>
<td>60 sec</td>
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</table>

4 shows tensile strength of the base material and the welded material at each low temperature, while Figs. 5 and 6 indicate elongation of the yielding points and longitudinal elastic modulus, respectively. Absorbed energy is shown in Fig. 7, in which low temperature characteristics of the base material and the welds are also clarified. No difference was observed between the base and the welded materials in respect of the physical properties as mentioned above, but both materials showed tendency of becoming brittle at -60°C. Figs. 8 and 9 show the result of experiments,
in which effect of load velocity to tensile strength of the base and the welded materials under low temperature atmosphere was examined. The result of such experiments showed that both of the materials had similar tendency, except that a tendency of becoming slightly brittle was observed with the welded material beyond the yielding point at \(-60^\circ C\). From the result of experiments, various relationships between the base and the welded materials were investigated and their results are shown in Figs. 10—14:—viz. relationship of tensile strength, low temperature and load velocity in Fig. 10; yielding point elongation, low temperature and load velocity in Fig. 11; tangent modulus, low temperature and load velocity in Fig. 12; each secant modulus at \(-60^\circ C\), low temperature and load velocity in Fig. 13; and absorbed energy, low temperature and load velocity in Fig. 14. Effect of load velocity was clearly observed, and both the base and the welded materials showed the tendency of becoming brittle especially at high speed of 500mm/min. under low temperature of below \(-20^\circ C\). Effect of notch was then investigated. Dumb-bell type specimens of 10mm. in breadth with V-shaped notches of 60° in notch angle and 2mm. in depth cut at center on both longitudinal sides were prepared for this purpose. As for the welded material, notch was cut at the weld. Results of experiments with the base and the welded materials are shown in Figs. 15 and 16 respectively, from which it is observed that even the
**Fig. 8** Effect of load velocity to tensile strength of the base material under low temperature atmosphere.

**Fig. 9** Effect of load velocity to tensile strength of the welded material under low temperature atmosphere.

**Fig. 10** Relationship of tensile strength, tension speed and low temperature of the base material and the welded material.

**Fig. 11** Relationship of elongation on yielding point, tension speed and low temperature of the base material and the welded material.
base material yields at very little elongation and breaks down with elongation of less than 30%. With regard to the welded material, specimens were observed to break down before reaching yielding value under low temperature below -40°C. No difference was observed between the base and the welded materials when the temperature was above -30°C. Figs. 17—21 show results of comparative investigations in relation to experiments done with the base and the welded materials:—viz. tensile strength, low temperature and notch effect are shown in Fig. 17; yielding point elongation, low temperature and notch effect in Fig. 18; stress concentration ratio, low temperature and notch effect in Fig. 19; longitudinal elastic modulus, low temperature and notch effect in Fig. 20; and absorbed energy, low temperature and notch effect in Fig. 21. From these experiments, it was found that notch effect existed both in the base and the welded materials. Notch effect was also found to affect greatly the physical property of the welded material under low temperature below -40°C and showed tendency of causing brittleness. Fracture of the base and the welded materials under low temperature was then examined. Photo. 1 shows the fractures occasioned between -50°C and -70°C (base material on the left side and welded material on the right). As for the base material, ductile fracture was observed throughout the range down to -70°C, while the welded material showed ductile fracture down to -60°C, without any remarkable plastic deformation around the fractured part, in spite of the fact that the stress-strain curve of the welded

![Fig. 12 Relationship of tangent modulus, tension speed and low temperature of the base material and the welded material.](image1.png)

![Fig. 13 Relationship of secant modulus, tension speed and low temperature of the base material and the welded material.](image2.png)

![Fig. 14 Relationship of absorbed energy, tension speed and low temperature of the base material and the welded material.](image3.png)
Fig. 15 Notch effect to tensile strength of the base material under low temperature atmosphere.

Fig. 16 Notch effect to tensile strength of the welded material under low temperature atmosphere.

Fig. 17 Relationship to tensile strength and low temperature for notch effect of the base material and the welded material.

Fig. 18 Relationship to yielding point elongation and low temperature for notch effect of the base material and the welded material.
Fig. 19 Relationship to stress concentration factor and low temperature for notch effect of the base material and the welded material.

Fig. 20 Relationship to longitudinal elastic modulus and low temperature for notch effect of the base material and the welded material.

Fig. 21 Relationship to absorbed energy and low temperature for notch effect of the base material and the welded material.

material was similar to that of the base material until they reached low temperature. Effect of load velocity appeared on the fracture is shown in Photo. 2, from which it was found that load velocity of 50mm/min. under −60°C apparently caused ductile fracture, while load velocity of 500mm/min. caused partial ductile fracture, thus the effect of load velocity became clear under −60°C. Photo. 3 shows the effect of notch as appeared on fracture. From these pictures the notch effect under low temperature was clearly observed both with the base and the welded materials, and plastic deformation around fractured part became very small even with the base material when the temperature was below −30°C. The welded material
formed brittle fracture when the temperature was below \(-50^\circ C\). Fracture was then examined by X-ray diffraction photography. Photo. 4 shows fractures of the base material at each temperature, from which it was confirmed that the material broke down by ductile fracture under the temperature down to \(-60^\circ C\) after molecular orientation in plastic deformation. X-ray diffraction photographs of the welded material are shown in Photo. 5. It was confirmed with these photographs that the fracture occurred on the welded material.
showed the same fractures as that of the base material within the range of temperature down to $-20^\circ$C, and that when the temperature went down to $-60^\circ$C the material broke down by brittle fracture under the same molecular structure as before. Change in microscopic structure occasioned by welding was then investigated by E.S.R. Figs. 22–25 show E.S.R. spectra of the base material and of the welded material at each welding temperature. No formation of non-coupling electron by welding was observed in these spectra, and the welded material seemed to be in a stable molecular structure as before.

Photo. 5 X-ray photographs on the fracture of welded polyethylene at each temperature.

Fig. 22 Electron spin resonance spectrum of the base material.
(Sample—P.E base material, temp.—20$^\circ$C, out put—8.0mW, field—3360G±250G, sweep time—16min, mod.—100KHZ, 6.3G, amplitude—100×10, response—0.3)

Fig. 23 Electron spin resonance spectrum of the welded material (welding temperature : 150$^\circ$C).
(Sample—P.E welded material, temp.—20.5$^\circ$C, out put—2.3mW, field—3360G±100G, sweep time—16min, mod.—100KHZ, 6.3G, amplitude—2.5×100, response—0.01)
CONCLUSION

The following summary can be made from the results of the present experiments.

Tendency of low temperature characteristics of the welded material is generally similar to that of the base material, except that a change occurs at $-60^\circ C$. Effect of load velocity is observed both on the base and the welded materials, and this effect becomes bigger when the temperature is low and load velocity is high. Notch effect is also observed both on the base and the welded materials, and this effect appears bigger with the welded material under the temperature of below $-40^\circ C$. Correlations are observed between fractured surface and mechanical testing results, as well as between X-ray diffraction pattern and mechanical testing results. No formation of non-coupling electron by welding is observed with E.S.R. spectrogram.

ACKNOWLEDGMENT

The authors would like to express sincere thanks to Sumitomo Bakelite Co. Ltd. for preparing to base materials.

REFERENCES

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