

Study on Breakdown Characteristics of Polymer Material at the Super Low Temperature Environment

Kyu Jin Shim¹, Sang Chul Lee¹, Young Gem Kim¹, Lubi Rahadiyan¹,
Hyo Min Jeong², Han Shik Chung²

¹Graduate School, Department of Mechanical and Precision Engineering, Gyeongsang National University, Tongyeong, KOREA

²School of Mechanical & Aerospace Engineering, Gyeongsang National University, Tongyeong, KOREA

Abstract: Resources recycling are very important and urgent technology for world industry. Development of waste recycling process includes environment protection and resources aspect. This process is very important for raw material of plastic industry, and the profit from this process is going to contribute national revenue. Especially waste plastic materials, if this process is not performed, it will cause serious problem for our environment. Therefore, recycling process technology of macro molecular material such as plastic is very important to be developed. The system for the treatment temperature (Tg) of waste material by using liquefied gas with super low temperature and technology is proposed for plastic recycling process. In addition, In this study, Impact energy is obtained for comminution of the low temperature in industry waste PE, PP, PVC material. The result of impact strength PE, PP and PVC in the super low temperature experiment at $-80 \sim -86^\circ\text{C}$ is compared with normal temperature at 18°C . It is found that the impact strength of PE, PP, and PVC decrease about 94.6%, 90.57%, 93.12% respectively

Keywords: Liquefied Gas, Super Low Temperature, Impact strength, Plastic, Comminution

NOMENCLATURE

T : Temperature [$^\circ\text{C}$]
 α : Initial angle [$^\circ$]
 β : Angle after collision with specimen [$^\circ$]
U : Impact value [$\text{N}\cdot\text{cm}/\text{cm}^2$]
E : Impact energy [$\text{N}\cdot\text{cm}$]
A : Area of notch cross section [cm]
W : Weight of hammer [kg]
R : Radius of hammer arm [cm]
h1 : Initial height of the hammer [cm]
h2 : Height of hammer after collision [cm]

1. INTRODUCTION

Resources recycling are very important and urgent technology for world industry. Development of waste recycling process includes environment protection and resources aspect. [1-5], this process is very important for raw material of plastic industry, and the profit from this process is going to contribute national revenue. In case of waste plastic materials, if this process is not performed, it will cause serious problem for our environment. Therefore, recycling process technology of macro molecular material such as plastic is very important to be developed. [6-8] The system for the treatment temperature (Tg) of waste material by using liquefied gas with super low

temperature and technology is proposed for plastic recycling process.

In this study, Impact energy is obtained for comminution of the low temperature in industry waste PE, PP, PVC material. In order to obtain glass transition temperature of each material, the chamber is made and the temperature is controlled. This system will achieve glass transition temperature from -120°C , which is transition temperature of PE, up to ambient temperature. With this, delay time is studied at the each transition temperature and information of glass transition temperature is acquired

2. PREPARING THE MANUSCRIPT DESIGN OF VAPORIZATION SYSTEM BY USING LIQUEFIED NITROGEN

In this study, liquefied nitrogen is utilized as cooling energy. To utilize the cooling energy, direct cooling energy environment and indirect cooling energy environment was constructed, and then this system is used to conduct experimental study of glass transition temperature.

Figure 1 illustrate schematic diagram of experimental equipment in order to used cooling energy system.

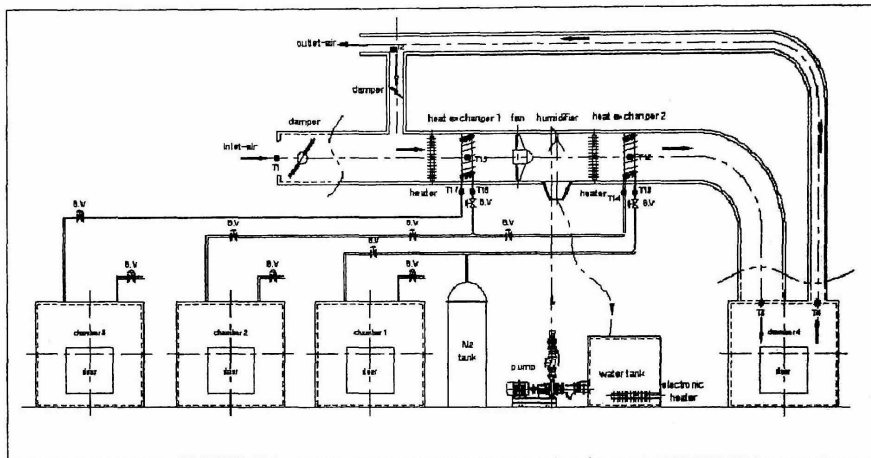


Figure 1: System of the Waste Matter Treatment Tg by Using Liquefied Gas with Super Low Temperature.

In this system, nitrogen from LN₂ tank is supplied to direct cooling energy chamber. At the same time, indirect cooling energy chamber is cooled by heat exchanger which is connected to LN₂ tank. Say chamber 1, 2 and 3 are direct cooling energy environment. Chamber 4 is indirect cooling energy environment. At the schematic diagram (Fig. 1), chamber 1 is super low temperature nitrogen gas from which nitrogen is discharged into the chamber at once. LN₂ tank also supplies super low temperature nitrogen to heat exchanger 2. After passing heat exchanger 2, this nitrogen will be sent to the chamber 2. Therefore chamber 2 temperature will be higher than chamber 1. Likewise, the heat exchanger 2 receive nitrogen LN₂ tank and transmit it to the chamber 3. Because air inlet temperature at heat exchanger 1 is higher than air inlet temperature at heat exchanger 2, therefore temperature of chamber 3 will be higher than chamber 2. Meanwhile, indirect cooling energy from the air passes heat exchanger 1 and 2. So this chamber temperature will be higher than direct cooling energy chamber.

First, testing specimen of plastic and rubber produce, after the test, the physical properties of material at the glass transition temperature in each chamber are obtained and ensure the whole process technology for comminution.

Figure 2 illustrate cooling energy system which is drawn by using CATIA. First, super low temperature nitrogen is discharged from the LN₂ tank, Passing through heat exchanger 1 and heat exchanger 2 and discharged to the liquid dewar. Inlet air from outside was suck by fan. This inlet air passes heat exchanger 1 and heat exchanger 2 respectively. This air is used to cool down chamber in order to reach glass transition temperature for experimental plastic and after exchange cool energy to the chamber, this air is rejected to the environment.

Figure 3 depict experimental equipment in order to make cooling environment.

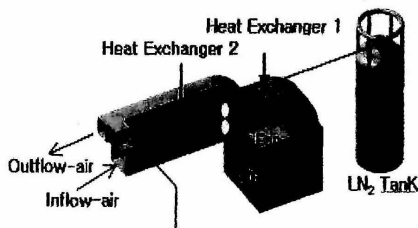


Figure 2: Design of heating and cooling system

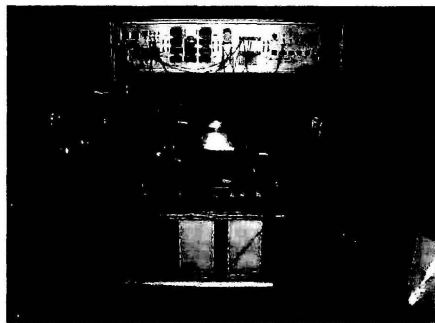


Figure 3: Experimental system Apparatus

Upper panel is controller unit for controlling entire system and measuring temperature of each part. And this experimental is made up 2 Heat Exchanger and a Fan.

3. IMPACT TEST USING CHARPY' METHOD

Basic experiment is performed by using CHARPY' for impact testing of high molecular substance such

as plastic. The purpose of this impact testing is to measure impact resistance, ductility and brittleness of plastic material by CHARPY' impact testing. [9-13] Ambient impact tester and super low temperature condition is approached at this experimental study. Figure 4 is CHARPY' impact tester which is measured impact strength under glass transition temperature at the experiment apparatus manufactured for cool energy environment construction. First, plastic was set on the anvil which is located at bottom left. Second, hammer was lifted up under specific angle and drop [14-18]. Finishing cut the plastic specimen, hammer swing one times, going through anvil and stopped by bend brake. Finally, quantity of absorption energy can be read from impact gage in order to obtain the impact strength.

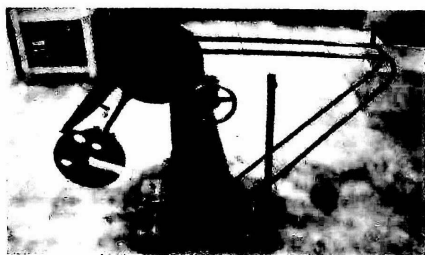


Figure 4: CHARPY' impact tester

Figure 5 is Principle of CHARPY' impact tester. R is radius of hammer arm, α is initial angle, β is angle after collision with specimen, h_1 is initial height of the hammer, h_2 is height of hammer after collision, W is weight of hammer. Impact energy for cutting specimen is calculated as follows [18-19]

$$E = Wh_1 - Wh_2$$

$$Wh_1 = W(1 - \cos \alpha)$$

$$Wh_2 = W(1 - \cos \beta)$$

Impact energy E is

$$E = WR (\cos \beta - \cos \alpha)$$

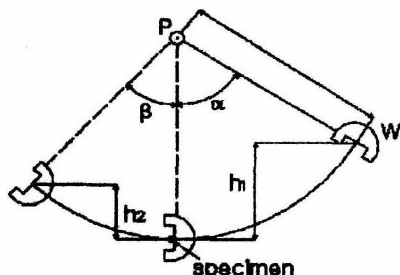


Figure 5: Principle of CHARPY' impact tester

Impact value U is

$$U = \frac{E}{A}$$

$$\therefore U = \frac{WR(\cos \beta - \cos \alpha)}{A} \text{ kgf} \cdot \text{m/cm}^2$$

(A: Area of notch cross section)

V or U notch is prepared at middle cutting part of specimen to show stress concentration effect.

4. INVESTIGATION AND RESULT FO EXPERIMENT

This test is using PP, PE, PVC standard specimen(10mm×10mm×55mm) and impact test is conducted at ambient temperature (18℃), at super low temperature (-196℃), exposure specimen in ambient temperature after 1 minute and 2 minute.



Figure 6: Specimen of PP, PE and PVC

Figure 6 shows three type of specimen (PP, PE, PVC) that is tested in this experimental. These specimens were tested 5 times for each of 20 specimens. Next picture shows LN₂ gas in gas cylinder to set the specimen environment under super low temperature. Each specimen is measured for 5 times. Except for ambient temperature test, PP, PE and PVC specimens were only tested one time.



Figure 7: Lay up Liquid Dewar of LN₂

4.1 Temperature distributions of PP, PE and PVC

Figure 8~10 is temperature distributions of PE PP, PVC in the gas cylinder during 10 minute, 20 minute and 30 minute in the super low temperature. In this graph, each specimen is measured at the ambient temperature for 10 minute. At the first time, specimen temperature show at intervals of $-5^{\circ}\text{C} \sim -10^{\circ}\text{C}$ under the exposure from gas cylinder to ambient temperature. But immediately, each specimen display relatively same temperature distribution. To measure temperature of specimen, T type thermocouple was utilize to measure temperature down to -200°C . This thermocouple was inserted into 10mm hole at middle-left position. This conditions is employed to the PP, PE, PVC and disregard adiabatic characteristic of specimen. In a CHARPY[®] impact tester, length of hammer is 76cm, Weight of hammer is 30kg, initial angle is 30° for all condition.

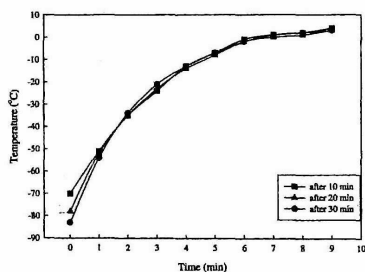


Figure 8: Temperature distributions of PE

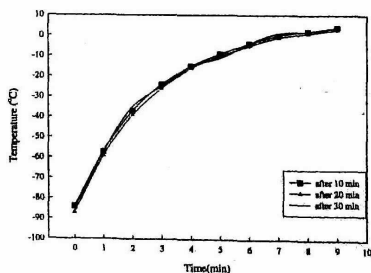


Figure 9: Temperature distributions of PE

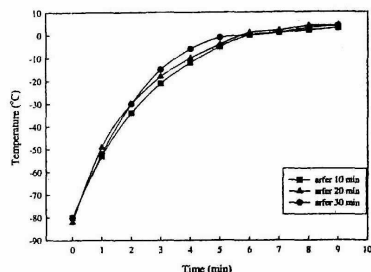


Figure 10: Temperature distributions of PVC

4.2 Impact strength of PP, PE and PVC for each temperature

Table 1~3 shows impact strength of specimen for each temperature which is calculated by equation (2). PP shows the highest impact strength of all testing material. Instead of cut it just bent. Value of impact strength was $367.39 \text{ N} \cdot \text{cm}/\text{cm}^2$. Also, smallest impact strength occur when the test is under the condition of super low temperature LN_2 gas which the plastic only get short exposure. All kind of material showed same result impact strength by $19.59 \text{ N} \cdot \text{cm}/\text{cm}^2$.

Table 1: Impact strength of PP

T (°C)	18°C	-86°C	-58°C	-37°C
Impact Strength	367.39	19.59	19.59	56.95

Table 2: Impact strength of PE

T (°C)	18°C	-86°C	-58°C	-37°C
Impact Strength	207.76	19.59	29.16	29.16

Table 3: Impact strength of PVC

T (°C)	18°C	-86°C	-58°C	-37°C
Impact Strength	284.91	19.59	19.59	29.16

Figure. 11 shows result impact strength of PP, PE, PVC. When the time is 0, X axis shows result of PP impact strength at normal temperature is very high.

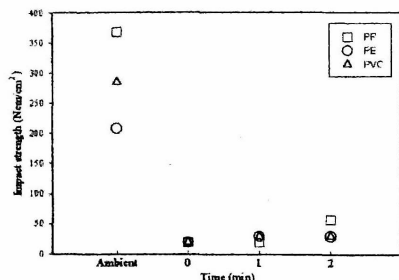


Figure 11: Impact strength distributions of PP, PE and PVC

At the axis equal to 1 (when the material get short exposure to normal temperature), Y axis shows the value of impact strength of PP, PC and PVC have same results. The test result of three materials at ambient temperature exposure after 1 minute and 2 minute only shows little variation.

4.3 Observation of cutting surface of PP, PE, PVC

The picture of four different temperatures cutting surface, when hammer cut the specimen of PP, PE and PVC, is taken by close photograph digital camera. First, picture at ambient temperature, second, at quick exposure from LN₂ gas cylinder to ambient temperature. Third, after exposure at ambient temperature during 1 minute and the fourth is after 2 minute of exposure.

Figure 12~17 shows cutting surface after measured by CHARPY impact strength with two piece of PP, PE and PVC

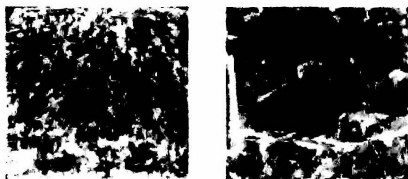


Figure 12: PE Fracture surface at 18°C and -80°C



Figure 13: PE Fracture surface at -53°C and -35°C



Figure 14: PE Fracture surface at 18°C and -86°C



Figure 15: PE Fracture surface at -58°C and -37°C



Figure 16: PE Fracture surface at 18°C and -80°C

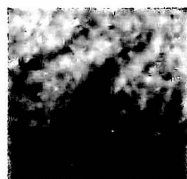
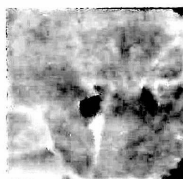


Figure 17: PE Fracture surface at -50°C and -30°C

Figure 12 ~ 17 compare cutting surface at normal temperature (18°C) and quick (-86°C~-80°C) exposure to ambient temperature. By using this picture, characteristic of impact strength at low temperature will be able to study. In the figure 12 ~ 17 hammer smash the specimen from the bottom to upper direction. At the first time, cutting surface (b) showed smooth fracture which exposed to ambient temperature. In the contrary ambient temperature (18°C) specimens show rough fracture. (Left side photographs)

This is the reason why glass transition temperature for specimen with super low temperature LN₂ gas has brittleness characteristic. By comparing impact strength result for instance PP, result of impact strength at ambient temperature (18°C, 207.76 N · cm/cm²) is 20 times higher than at the low temperature (-80°C, 15.59 N · cm/cm²)

5. CONCLUSION

A chamber with liquid LN₂ gas is installed for constructing super low temperature system in order to develop technical treatment of waste matter handling using super low temperature liquid gas.

Experiment for testing PP, PE and PVC impact strength at super low temperature is conduct in this study.

This experimental study shows that the impact strength of PP, PC and PVC specimen is very low at super low temperature condition. This material is very brittle at super low temperature. Therefore this condition is very suitable for PP, PC and PVC waste recycling process

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