CHARACTERISTICS AND APPLICATION OF AN EPOXY RESIN HAVING THERMOPLASTIC BEHAVIORS

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Keywords: *epoxy, recycle, reusable, thermoplastic, toughness*

1. General Introduction

Thermoplastic epoxy used in this study has been obtained through polymerization of epoxy and phenol, in which these are linearly connected by consecutive reactions. As a result, it was found that thermoplastic polymer with no crosslinking was formed and the polymer showed typical thermoplastic behaviors such as reforming capability after molding (Fig. 1) and solubility in organic solvents [1].

In this study, evaluation on the thermoplastic epoxy was performed in two ways. One was examined as cured resin itself. The other was in forms of fiber reinforced plastics (FRP). Mechanical, physical and thermal properties were measured for the cured parts. Also possibility on reusability or recyclability was examined. This was carried out through secondary bonding process, reforming process, and dissolving process using organic solvents.

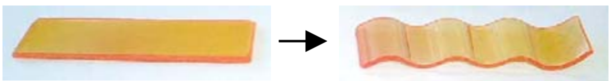


Fig.1. Reforming of thermoplastic epoxy by secondary molding .

2. Experimental

2.1. Materials

The thermoplastic epoxy (XNR6850A) and its curing agent (XNH6850AY) were produced by Nagase Chemtex(NCX), Japan. For comparison, a BPA type thermosetting epoxy with its curing agent was also obtained from Nagase Chemtex(NCX).

Reinforcement glass fabric, #7628 (plane, 209 g/m^2) and glass/epoxy prepreg, HD430, (glass fabric:#7628, BPA type thermosetting epoxy, resin content:40 wt.%), were produced by Hankuk Carbon.

2.2. Preparation of the cured resin

Cured resin specimen of thermoplastic epoxy, and thermosetting epoxy for examination were prepared by mold casting. Curing conditions of each resin are shown in Table. 1. For the mixing of thermoplastic epoxy, XNR6850A, it was heated to 100 ℃ in temperature controlled oil bath and stirred for 10 minutes. The curing agent, XNH6850AY, was added into the heated resin with stirring the solution for a further 3 min at 100 ℃. The mixture was immediately poured in the mold. The mixing ratio was XNR6850A : XNH6850AY = 50 : 1.

Contents	Thermoplastic Epoxy	Thermosetting Epoxy
Manufacturer	NCX	NCX
Product Name	XNR6850A+XNH6850AY	XNR6815+XNH6815
Curing Condition	135℃ x 1hr 30min	25℃ x 24hr + 80℃ x 2hr

Table.1. Curing conditions for the cured resin.

2.3. Preparation of the FRP

FRP specimens were prepared in 3 different types. Type Ⅰ was prepared by hot press molding using 8 or 16 layers of HD430 glass/epoxy prepreg. Curing condition for Type Ⅰ was 2hr at 170 ℃ under 25 kgf/cm^2 pressure. Type Ⅱ was prepared by hand lay-up process using 4, 8 or 16 layers of #7628 glass fabric with XNR6850A/ XNH6850AY. Curing condition of Type Ⅱ was 135℃ for 1 hour and 30 minutes. To evaluate the possibility of secondary bonding and reforming, Type Ⅲ was fabricated by secondary bonding of two Type Ⅱ panels having 4 layers. Secondary bonding condition was 20 minutes at 165 ℃ under 25 kgf/cm^2 pressure.

3. Results and discussion

3.1. Characteristics of the cured resin

In spite of thermoplastic characteristics, the thermoplastic epoxy showed approximately 90% of tensile and flexural modulus comparing to thermosetting epoxy. Moreover, Charpy impact value and K_{1C} showed approximately 250% of improvement versus thermosetting epoxy as shown in Table. 2. K_{1C} of the thermoplastic epoxy is 2.0 MPam$^{1/2}$ which is much higher than that of liquid rubber modified epoxy, known as 1.30 MPa·m$^{1/2}$ [2, 3]. And also thermoplastic epoxy, as shown in Table.3 and Fig.2, showed higher fracture toughness value than thermoplastics such as polymethyl methacylate(PMMA), polystylene(PS) and polyester but lower than Nylon-6,6 [4].

Contents	Thermoplastic Epoxy	Thremosetting Epoxy
Flexural strength (MPa)	106	110
Flexural modulus (MPa)	2600	2900
Tensile strength (MPa)	62	72
Tensile modulus (MPa)	2510	2860
Charpy impact value (V Notch)(J/mm2)	12.2	5.0
K_{1C} (MPa·m$^{1/2}$)	2.0	0.85
Tg（℃）	95	90

Table.2. Comparison of thermoplastic and thermosetting epoxy on cured resin properties.

Contents	Fracture toughness, K_{1C} (MPa·m$^{1/2}$)
Thermoplastic Epoxy	2
Thermosetting Epoxy	0.85
Nylon-6,6 [4]	2.5
PMMA [4]	1.6
PS[4]	1.1
Polyester [4]	0.6

Table.3. Fracture toughness values of thermoplastic epoxy, thermosetting epoxy and other thermoplastics

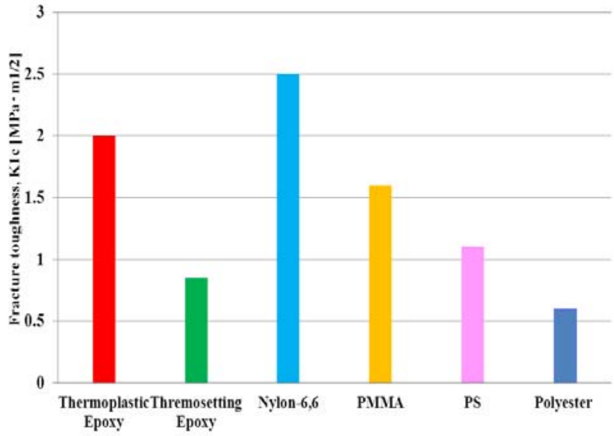


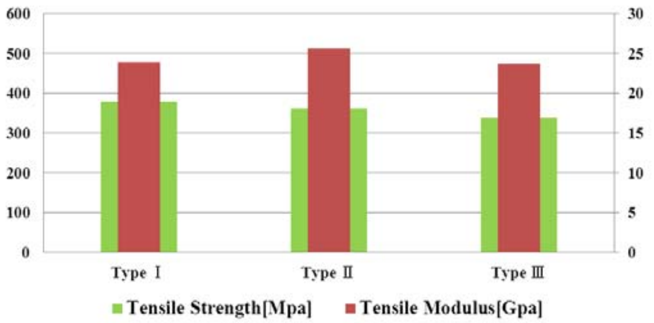
Fig.2. Comparison of fracture toughness of various thermoplastics

3.2. Mechanical properties of FRP

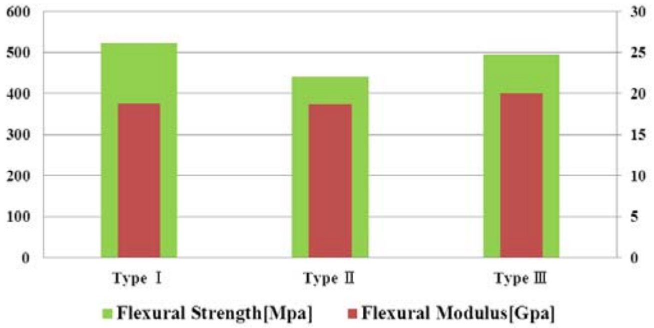
Mechanical properties on 3 different types FRP are listed and compared in Table. 4, Fig. 3 and 4. Although the tensile, flexural, compressive and interlaminar shear strength (ILSS) of Type Ⅱ showed lower values than Type I, The tensile, compressive and flexural modulus of Type Ⅱ are similar with Type I, which means the thermoplastic epoxy maintained the good mechanical properties of typical epoxy. Type Ⅲ is as similar with Type Ⅱ, which means that the cured thermoplastic FRP can be bonded again even after curing. The SEM image in Fig.5 shows that there is no difference on inter-laminar area where the secondary bonding is occurred.

Contents	Type Ⅰ (Thermosetting Epoxy)	Type Ⅱ (Thermoplastic Epoxy)	Type Ⅲ (Thermoplastic Epoxy)
Tensile strength (MPa)	379	361	339
Tensile modulus (GPa)	24	25	24
Compressive strength (MPa)	357	271	282
Compressive strength (GPa)	23	23	22
Flexural strength (MPa)	523	441	494
Flexural modulus (GPa)	19	19	20
ILSS (MPa)	61	56	56

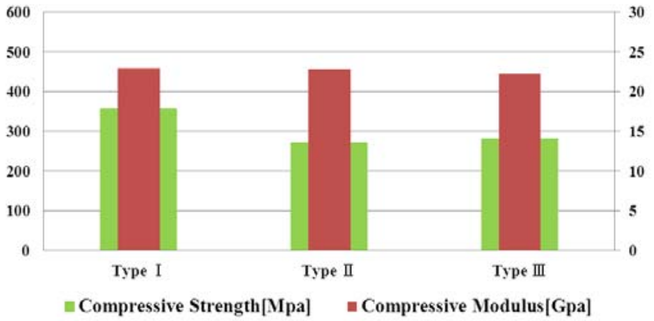
Table.4. Mechanical properties of Type Ⅰ, Ⅱ and Ⅲ.



(a)



(b)



(c)

Fig.3. Comparison of mechanical properties of Type Ⅰ, Ⅱ and Ⅲ: (a) tensile, (b) flexural and (c) compressive.

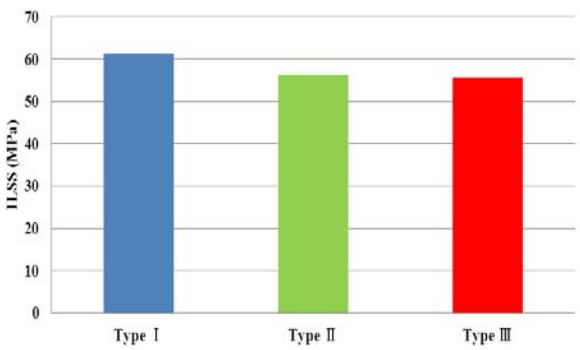
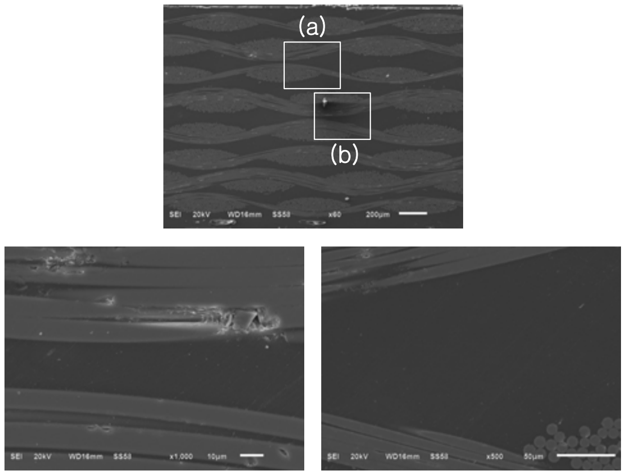


Fig.4. Comparison of ILSS of Type Ⅰ, Ⅱ and Ⅲ.



(a) (b)

Fig.5. Cross section of (a) secondary bonded and (b) co-cured inter-laminar area.

3.3. Corrosion resistance

Corrosion resistance of Type Ⅱ was examined under acid and alkali such as 10 wt. % of H_2SO_4 and NaOH (Fig. 6 and 7). The changing of the weight of the FRP was measured for 20 days. If the degradation is occurred, the water penetrates into FRP and the weight of FRP is increased. Type Ⅱ showed only 0.17 wt. % of increase after immerging under 10 wt. % of H_2SO_4 for 20 days and only 0.19 wt. % of increase after immerging under 10 wt. % of NaOH. It was confirmed that Type Ⅱ based on thermoplastic epoxy has good corrosion resistance. It is probably that the strong ether structure of thermoplastic epoxy polymer shows good resistance against acid and alkali.

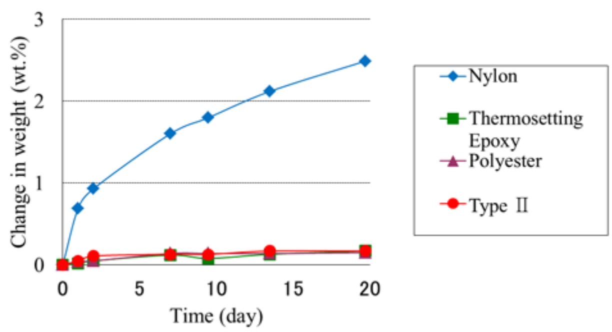


Fig.6. Weight change of Type Ⅱ, thermosetting epoxy, polyester and Nylon after immerging in 10 wt. % of H_2SO_4.

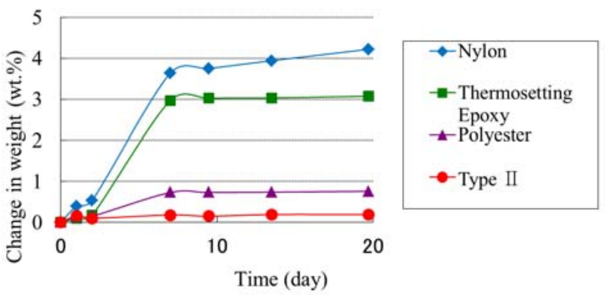


Fig.7. Weight change of Type Ⅱ, thermosetting epoxy, polyester and Nylon after immerging in 10 wt. % of NaOH .

3.4. Solubility in organic solvent

The solubility using Type Ⅱ was examined in organic solvents. Type Ⅱ was insoluble in non-polar solvents such as toluene, hexane. Meanwhile, Type Ⅱ FRP was dissolved in polar solvents such as acetone, tetrahydrofuran and dimethylformamide as shown in Fig.8. The fiber and the resin were successfully separated. It was found that this result will be a principle of recycle or reuse of FRPs based on thermoplastic epoxy.

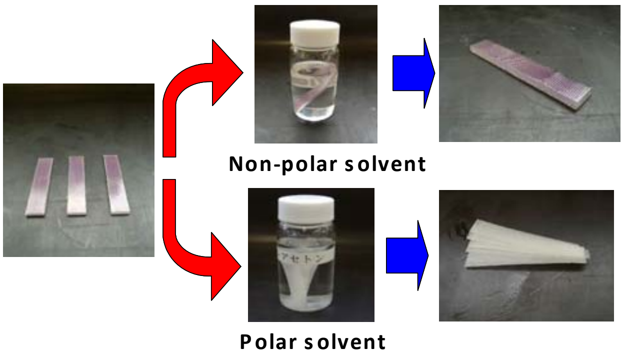


Fig.8. Comparison of solubility after 3 days immerging of thermoplastic epoxy matrix FRP in non-polar (toluene) and polar solvent (acetone).

4. Conclusion

The cured thermoplastic epoxy showed excellent toughness properties such as high Charpy impact value and $K_{1}c$ compared with the cured thermosetting epoxy. Unlike typical thermosetting epoxy FRP, this thermoplastic epoxy FRP can be processed in low pressure and low temperature. Moreover, the FRP based on thermoplastic epoxy showed not only high tensile and flexural properties but also recycle or reuse properties confirmed by solubility test and SEM observation. It is expected that the new recyclable and reusable composites are developed through our study.

References

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