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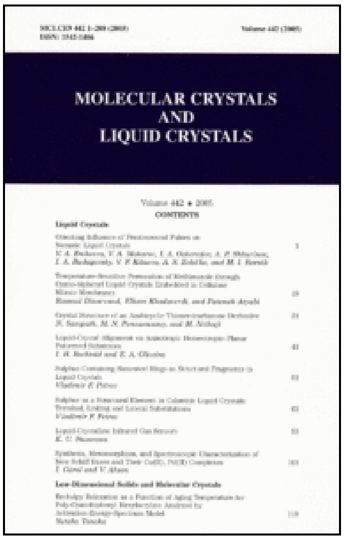

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
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Effect of Material Properties of Anisotropic Conductive Films (ACFs) on the Reliability of Chip-On-Glass (COG) Assembly

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First published on: 11 November 2010

To cite this Article Hwang, Jin-Sang , Kim, Ju-Yeol , Ku, Dae-Young , Shin, Kyung Seok , Jeong, Young Chul , Kwon, Younghwan and Kwon, Oh Hyeong(2010) 'Effect of Material Properties of Anisotropic Conductive Films (ACFs) on the Reliability of Chip-On-Glass (COG) Assembly', Molecular Crystals and Liquid Crystals, 529: 1, 122 — 130

To link to this Article: DOI: 10.1080/15421406.2010.495887

URL: http://dx.doi.org/10.1080/15421406.2010.495887

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Mol. Cryst. Liq. Cryst., Vol. 529: pp. 122–130, 2010
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ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2010.495887

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The effect of material properties of anisotropic conductive films (ACFs) on the reliability of chip on glass (COG) assemblies was investigated. Two types of ACF were used in this study. ACF-A (50 wt%) is designed to have higher rubber resin content than ACF-B (11 wt%), in order to reduce the warpage of COG assembly. From the study on basic material properties, such as elastic modulus (E′), coefficient of thermal expansion (CTE) and glass transition temperature (Tg), ACF-B showed better properties than ACF-A. The temperature cycle reliability test showed that there were little differences between two ACF COG assemblies in spite of their different warpage level. But, results of high temperature storage test (100°C and 1000 hours) exhibited that the ACF-B COG assembly showed better performances due to the better material properties of ACF-B.

Keywords ACF (anisotropic conductive film); COG (chip on glass); material property; reliability; warpage

Introduction

The interconnection technology using anisotropic conductive films (ACFs) has been one of major packaging methods for flat panel display modules [1–4]. ACFs, a type of adhesive films, consist of a formulation of epoxy resins and curing agents as main ingredients with other additives like conductive particles. Epoxy resins are being used as the most common adhesive material by virtue of their high cohesive and adhesive strength, low shrinkage, and versatility in formulating and processing [5]. But, during the curing process for fabricating the COG assembly, residual stress and warpage

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are generated in the package due to the cure shrinkage and mismatch of the coefficient of thermal expansion between the substrates. Particularly, the resulting warpage in COG assembly can cause not only device failures, such as delaminations and die crack, but also assembly problems, such as dimension instability and non-coplanarity, etc, in the subsequent process [6]. To solve the warpage problem, several methods have been utilized by incorporating inorganic fillers [7] and adding low modulus rubber resins [8]. Incorporation of a low modulus rubber resin into the formulation of ACFs reduces the warpage phenomena in the COG assembly directly, because a rubber phase can relax the internal stress originated from the packaging process. But, increasing the rubber resin content can cause the deterioration of material properties of ACFs, especially in thermal stability. This can also affect seriously on the performance and reliability of the fabricated COG assembly. So, control of the basic material properties of ACFs has been of importance in the COG assembly.

In this paper, we have studied the reliability of COG assemblies fabricated by using ACFs with two different rubber resin contents. The basic properties of ACFs, such as thermal stability, E′, CTE, Tg and cure shrinkage, are determined as a function of rubber resin contents in ACFs. Then, the reliability tests for COG assemblies are performed in terms of a connection resistance during the environmental test, and the relationship between material properties of ACFs and the reliability of COG assemblies also investigated.

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Experimental

Materials Preparation

An epoxy based resin was used as a central adhesive resin in the formulation of ACFs, due to its good adhesion to various substrates, high glass transition temperature, and favorable melt viscosity requested for the bonding. An imidazole derivative was used for a curing agent, and Ni and Au coated polymer particles in 4 μm size were used as conductive particles. The ACF formulation consisting of the epoxy based resin, a rubber resin, and fine conductive particles were mixed uniformly, and then fabricated as dried films in 25 μm thickness on the top of the carrier PET film. The specifications of a test chip and a glass substrate used for the COG assembly were summarized in Table 1.

Table 1. Specifications of the test chip and the glass substrate

Specification	Glass substrate
Material	Glass, 0.8 mm thick
Final metallization	Au, 0.1 μm thick
Specification	**Test IC**
Size (mm × mm)	14 × 1.7
Bump material	Au (electroplated)
Bump height	18 μm
Bump size	50 μm × 50 μm
Bump space	20 μm

ACF COG assembly was fabricated along three steps as follow. First, ACF was pre-bonded to the glass substrate with the conditions of 80°C and 10 kgf/cm^2 for 3 sec. Then, the I/O pads on the chip and glass substrate were aligned each other. Finally, the thermo-compression bonding of the chip on the glass substrate using ACF was carried out with a bonding pressure of 100 gf/bump, a bonding temperature of 200°C and a bonding time of 5 sec.

Characterization

DSC (TA-Q100), calibrated with high purity indium and zinc standards, was used for studying on the cure kinetics of ACFs as a function of time. The thermal stability of cured ACF materials was investigated by measuring a weight loss with elevated temperature using TA Q-50 instrument. CTE, E′ and the degree of cure shrinkage were measured by using Seiko Instruments thermo-mechanical analyzer (TMA/SS 6100). Sample was subjected to a uniaxial tension mode from 30°C to 180°C with a heating rate of 5°C min^{-1} (Fig. 1) [9].

To investigate the reliability of ACF COG flip chip assembly, the connection resistance was monitored during the environmental tests, where high temperature storage test (100°C, 1000 hours) and temperature cycle test (−40°C to 100°C, 1000 cycles) were employed. The initial connection resistance was measured using 4-point probe method, and after each time interval, the connection resistance was measured until the completion of the environmental test.

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Results and Discussion

ACFs with two different rubber resin contents, ACF-A (50 wt%) and ACF-B (11 wt%), are prepared, and their physical and mechanical properties are presented in Table 2. ACF-B with 11 wt% of the rubber resin content shows higher elastic modulus, higher Tg and lower CTE than ACF-A containing 50 wt% of the rubber resin content. The thermal degradation behaviors of two ACFs are also investigated with thermo-gravimetric analyzer (TGA), as can be seen in Figure 2 and Table 2. From the TGA curves and data, ACF-A exhibited rapid decomposition, even at a

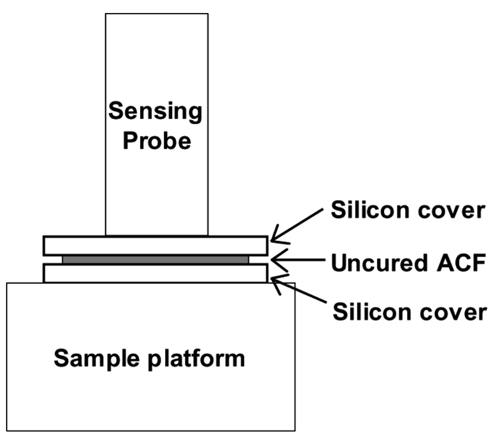

Figure 1. Schematic setup of ACF curing shrinkage measurement.

Table 2. Physical and mechanical properties of ACF-A and ACF-B

	ACF-A	ACF-B
CTE (ppm/°C)		
Below Tg	541.3	70.7
Above Tg	6,802	3,371
Modulus (MPa)		
30°C	213	1,295
160°C	10.8	26.8
Tg^{DMA} (°C)	111.5	123.9
Cross-link density (10^{-3} moles/cm^3)	0.981	2.434
Cure shrinkage (%)	0.414	5.784
TGA (%)		
Residue at 100°C	98.6	99.6
Residue at 200°C	97.8	99.6
Residue at 300°C	94.8	99.2

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lower temperature under 100°C, compared to ACF-B. One may postulate that the differences in these properties can be mainly attributed to the variations of cross-link density of cured ACFs caused by different rubber resin contents in the ACF composition. It is clearly seen with cure characteristics of ACFs measured by using DSC. Figure 3 shows DSC curves of ACF-A and ACF-B. Because ACF-A (50 wt%) have higher rubber resin content than ACF-B (11 wt%) in order to reduce the warpage of the COG assembly, the melt viscosity of ACF-A is expected to be higher than ACF-B. In addition, the concentration of reactive epoxy monomers in ACF-A decreased with increasing the rubber resin content. Therefore, it may be expected

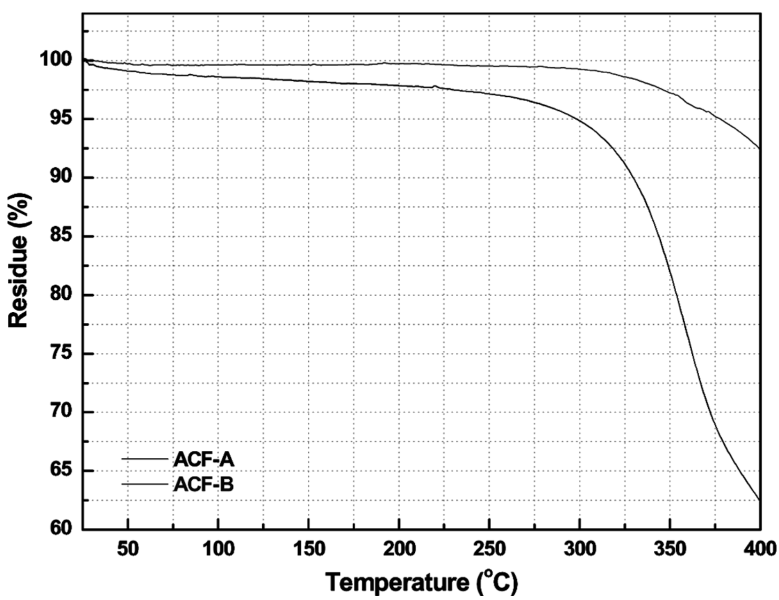

Figure 2. TGA thermograms of ACF-A and ACF-B.

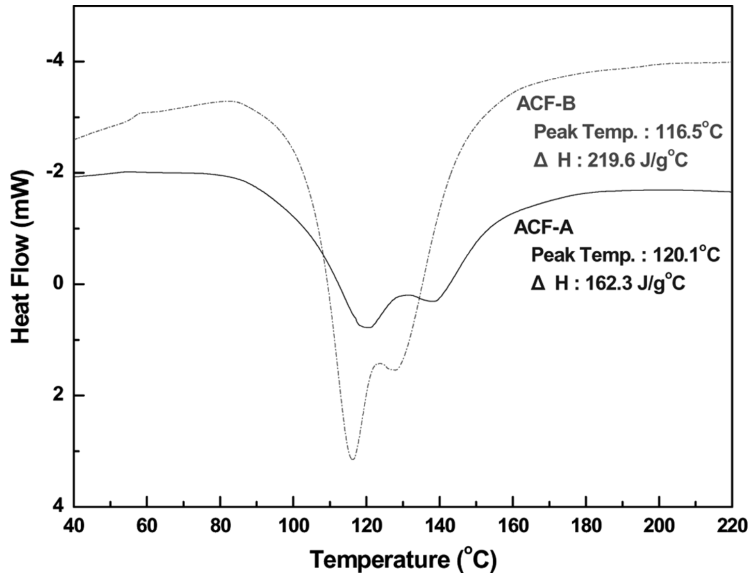

Figure 3. DSC thermograms of ACF-A and ACF-B.

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that the curing reaction is more difficult in ACF-A than in ACF-B. As a result, ACF-A shows higher curing peak temperature and lesser exothermic heat of cure, possibly resulting in lower degree of cross-link density, compared to ACF-B.

Along this line, the cross-link density is determined from the elastic modulus of ACF samples according to the rubber elasticity theory [10]:

$$\nu = \mathrm{Er}/3\mathrm{RT}$$

where ν represents the cross-link density (number of moles of chains per cm^3), R is the gas constant (8.314 J/K · mol), T is the temperature in Kelvin at 40°C above the glass transition temperature of samples, and Er is the elastic modulus. As shown in Table 2, ACF-B (2.434×10^3 moles/cm^3) has much higher cross-link density than ACF-A (0.981×10^3 moles/cm^3). This result clearly proves that cross-link density of ACFs is a major factor affecting on the material properties of ACFs.

Recently, the warpage behavior of the COG assembly is one of important concerns especially for large-sized LCD module using large-sized chip. High degree of the chip warpage on the COG assembly arises from high temperature gradient between the chip surface, where the temperature is as high as 200°C of the bonding temperature, and the glass substrate with normally room temperature. Therefore, the chip attached on the glass bends concavely after the COG bonding process.

We compare the warpage level of the COG assemblies fabricated with ACF-A and ACF-B, as shown in Figure 4. The warpage of the ACF COG assemblies are measured by using a surface profiler. After COG bonding process, half of the chip surface is scanned by using a contact type measurement with 0.2 μm resolution. As we have discussed previously that the elastic modulus of ACF has important effect on the warpage level of ACF COG assembly, and thus low modulus ACF is preferred [11], ACF-A COG assembly with relatively low modulus exhibited smaller warpage level than ACF-B COG assembly.

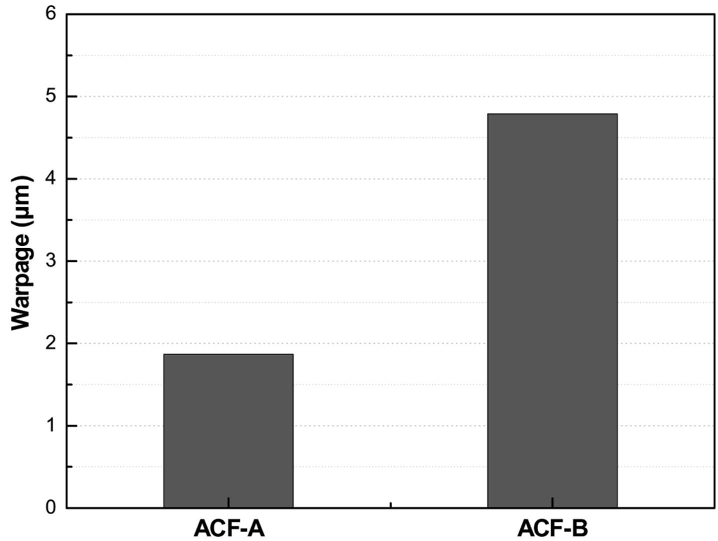

Figure 4. The warpage level of ACF-A and ACF-B COG assemblies.

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The reliability tests of the ACF COG assembly are performed with temperature cycle test and high temperature storage test. Figure 5 shows the temperature cycle test (−40°C to 100°C, 1000 cycles) result of the COG assemblies. It has been known for the initial contact resistance that lower cure shrinkage causes higher electrical contact resistance between conductive particles and bumps because of smaller binding force between chips and substrates. According the data on the cure shrinkage of ACF-A and ACF-B summarized in Table 2, ACF-B COG assembly is likely to show

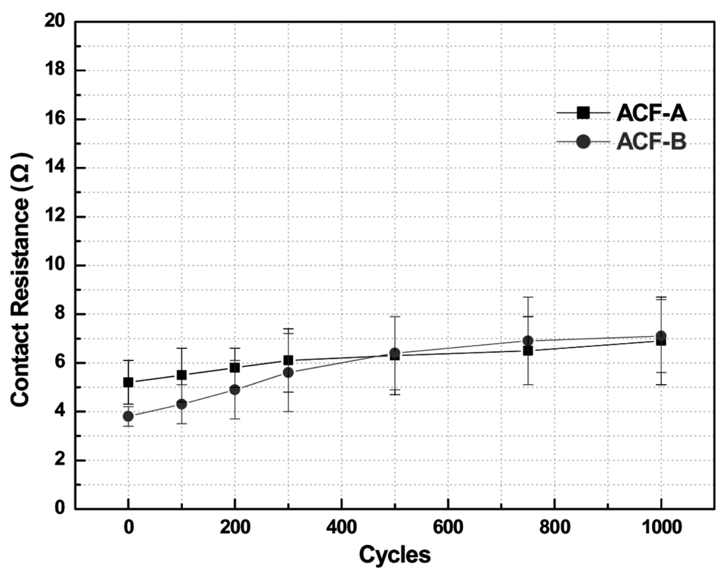

Figure 5. The changes of contact resistance of ACF-A and ACF-B COG assemblies during the temperature cycle test (−40°C to 100°C).

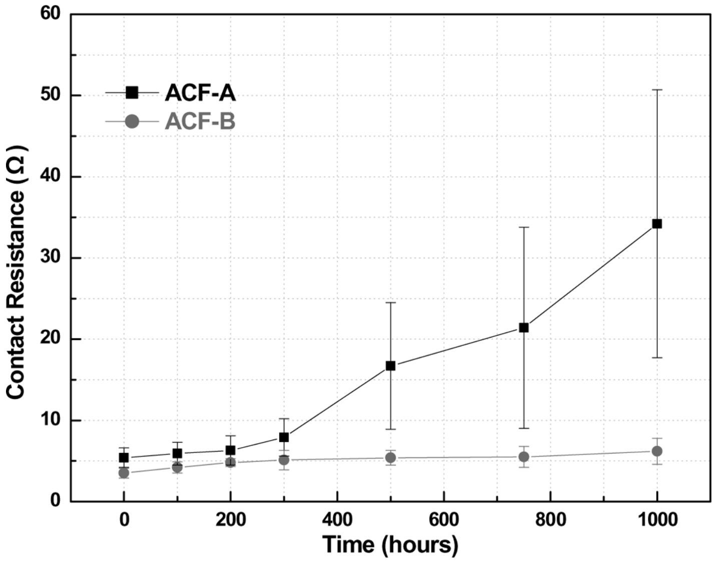

Figure 6. The changes of contact resistance of ACF-A and ACF-B COG assemblies during the high temperature storage test (100°C).

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lower initial contact resistance than ACF-A one, as confirmed in Figure 5. It also appears in Figure 5 that the contact resistance of ACF COG assembly increases with increasing the number of cycles, and the ACF-B COG assembly shows slightly higher contact resistance at the end of test than ACF-A COG assembly. In spite of higher warpage level of the ACF-B COG assembly, the contact resistance of both COG assemblies during the temperature cycle test is similar, which may be explained by lower CTE and shear strains in adhesive layer of the ACF-A COG assembly [7].

The changes in the contact resistance at the joint of the ACF COG assembly during high temperature storage test are shown in Figure 6. SEM cross-sectional pictures showing the deformation of conductive particles and the thermal degradation of adhesive matrix before and after 1000 hours of high temperature storage test in Figure 7 explain the contact resistance behavior of ACF COG assemblies.

Figure 7(a) and (d) represent the deformation of conductive particles as a function of cure shrinkage of ACFs. Compared to ACF-A COG assembly in Figure 7(a), ACF-B COG assembly in Figure 7(d) exhibits more deformed conductive particle, thus making larger contact area in between the conductive particles, bumps and pad surface, originated from increased binding forces between chips and substrates driven by higher cure shrinkage during the bonding process. Therefore, ACF-B COG assembly shows lower initial electrical contact resistance than ACF-A COG assembly.

The contact resistance values at the joint of ACF COG assemblies increase over the aging time, but the ACF-B COG assembly shows more stable resistance than ACF-A COG assembly. This is mainly due to the thermal stability and cure shrinkage of ACF samples. As the ACF COG assembly is exposed to high temperature, the adhesive matrix initiates the thermal degradation, and subsequently looses the contraction force. Therefore, initially deformed conductive particles can restore back to their original shape in a certain level and, as a result, defects of adhesive matrix,

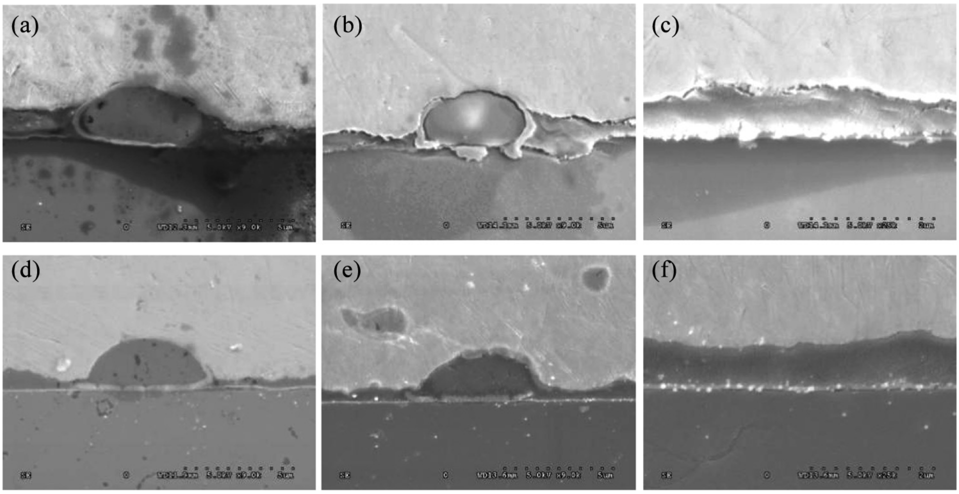

Figure 7. SEM pictures of deformed conductive particles and adhesive matrix as bonded ((a)-ACF-A, (d)-ACF-B) and after the high temperature storage test ((b),(c)-ACF-A, (e),(f)-ACF-B) in the COG assemblies.

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delaminations, and subsequent deterioration of the contact resistance are likely to occur. When compared in Figure 7(e) and (f), any defects in adhesive matrix, delaminations between interfaces, and restoration of conductive particles are not observed in ACF-B COG assembly (Figure 7(f)), because of good thermal stability and binding force due to enough cure shrinkage of ACF-B. But, in case of the ACF-A COG assembly, many delaminations between ACF, substrates and the conductive particle are visibly observed in Figure 7(b). Furthermore, serious cracks and delaminations are also monitored inside of ACF matrix in Figure 7(c). These delaminations and cracks are mainly due to the thermal degradation of the ACF-A material and may provide a detrimental route to the water absorption pass at high humid environment.

Conclusions

In this paper, we have investigated the relationship between material properties of ACFs and the reliability of COG assemblies. Two types of ACF, depending on the rubber resin content, were employed; ACF-A (50 wt%) and ACF-B (11 wt%). ACF-A with higher rubber resin content is designed to reduce the warpage of the ACF COG assembly. The rubber resin content in ACF formulations gives rise to reduction in the warpage of ACF COG assembly, but affects detrimentally on ACF material properties, such as E′, CTE, Tg, cure shrinkage, and thermal stability. Due to lower content of rubber portion, therefore, ACF-B material shows better material properties than ACF-A. The reliability performances of ACF COG assemblies have been also studied. In case of the temperature cycle reliability, the contact resistance of ACF COG assembly increases with increasing number of cycles, and the ACF-B COG assembly shows slightly higher contact resistance at the end of test than the ACF-A COG assembly. The results in high temperature storage test carried out at 100°C and for 1000 hours indicate better reliability of the ACF-B COG assembly. In conclusion, the reliability of the ACF COG assembly is strongly affected by the material properties of cured ACFs, and finding out the balance on them remains to be seen with further optimization.

Acknowledgments

This work is the outcome of 2008 Regional Industry Technology Development Program supported by Ministry of Knowledge Economy (MKE).

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