

Mismatch Analysis of TAB-on-Glass Connection with ACF

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ABSTRACT

Mismatch between outer lead bonds (OLBs) of a tape automated bonding (TAB) and a glass panel during fabrication is studied using the finite element method. A two-dimensional finite element model for the TAB-on-Glass (TOG) connector is presented for determining the deformation of the connector. The deformation of the TOG connector induced by residual thermal stresses are determined via a two-stage approach. At the first stage, the TOG connector is under heat and pressure. The anisotropic conductive film (ACF) in-between the TAB and glass panel is assumed to be in a melting condition so that both TAB and glass panel can expand freely. At the second stage, the connector is cooled down to room temperature and the ACF becomes solidified. The deformations of the connector at the two stages are determined in the finite element analysis in which the temperature dependence of material properties is considered. Effects of particular parameters on the mismatch between the OLBs are studied by means of a number of numerical examples. A method for compensation design of the lead locations of the OLBs is proposed. It has been shown that the compensation design can produce results that will avoid the occurrence of unwanted mismatch.

1. INTRODUCTION

Liquid crystal display (LCD) has become an important display device in the electronic industry in recent years. In the fabrication of LCDs, Tape Automated bonding (TAB) technology by which fine pitch interconnections between LCD panels and driver-IC TAB are made possible using an anisotropic conductive film (ACF) has been adopted for packaging the components of LCDs [1-7]. When compared with the conventional packaging methods, the use of TAB package technique can provide many advantages such as having smaller and lighter packaging, reducing chip size, increasing I/O pins on the chip, facilitating space reduction in LCD devices et al. Due to the advance in packaging technology, the finest interconnection pitch for LCD can be as narrow as 70 μm . As the interconnection pitch gets finer, the probability of having LCD failure induced by the mismatch between the outer lead bonds (OLBs) of the TAB and glass panel will be higher. The OLB mismatch is mainly caused by the thermally induced residual stresses in the cured ACF. Although some research work has been devoted to the thermal stress analysis of TOG connection, the failure of LCD induced by mismatch of OLBs is still a problem to be tackled. In this study, methods for mismatch analysis of TOG connection and compensation design of interconnection pitch are presented. The feasibility and applications of the proposed methods are demonstrated by means of a number of examples.

2. DESCRIPTION OF THE PROBLEM

The two-dimensional configuration of a TOG connection is shown in Fig. 1. Figs. 1a and 1b show, respectively, the connection with or without mismatch. Basically, the connection consists of three components, namely, a tape with outer leads, an ACF, and a glass panel with outer leads. The ACF is placed in-between the tape and glass panel and the three components are bonded together under heat and pressure. The curing cycle for the assembly is shown in Fig. 2. During heating, the ACF melts down and both the tape and glass panel expand freely in the lateral directions. When the assembly cools down, the ACF is solidified and the three components become an integral part. The material properties of the components are available in the literature and also listed in Table 1.

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3. MISMATCH ANALYSIS

The seriousness of mismatch developed in the TOG connection depends on the deformations of the three components. In the deformation analysis of the connection, the outer leads of the TAB and glass panel are not included in the formulation and their effects on the deformations of the components are neglected. Herein, the deformation analysis of the TOG connection is formulated on the basis of a two-dimensional model coupled with a two-stage deformational approach. At the first stage, the connector is under heat and pressure. The ACF is assumed to be in a melting condition and the TAB and glass panel can expand freely. The elongation of the TAB is calculated as

$$\delta_p = \alpha_p L_p \Delta T \quad (1)$$

where δ , α , L denote elongation, coefficient of thermal expansion, and length, respectively; ΔT is temperature rise; subscript P denotes TAB. The elongation of the glass panel is determined in a heat transfer analysis of the panel. At the second stage, the connector cools down to room temperature under no pressure and the ACF is transformed to a solid bar with temperature dependent material properties. The final deformations of the components of the connector are then analyzed using the two-dimensional finite element model shown in Fig. 3. It is noted that due to symmetry only one half of the TOG connector is used to establish the finite element model. The deformation analysis is then accomplished using the commercial finite element code NASTRAN [8]. Once the final deformation of the connector is determined in the above analysis, the mismatches between the outer leads of the TAB and those of the glass panel can be calculated as

$$s_i = \tilde{x}_{ip} - \tilde{x}_{ig} \quad (2)$$

where s_i is the mismatch between the i th outer lead of the TAB and that of the glass panel; $\tilde{x}_{ip}$, $\tilde{x}_{ig}$ are the coordinates of the i th outer leads of the TAB and glass panel after deformation, respectively.

4. NUMERICAL EXAMPLES

The feasibility and applications of the aforementioned method are demonstrated by means of several examples. The material properties in Table 1 and the curing cycle of Fig. 2 are used to analyze the mismatch of the TOG connector in Fig. 1. At the first stage, the assembly is heated up from room temperature to 280 °C. In the heat transfer analysis of the assembly, it has been found that the temperature rise in the TAB is 172 °C. The temperatures at the top and bottom surfaces of the glass panel are 172 °C and 60 °C, respectively. The elongations of the TAB and glass panel are 12.98mm and 13.629mm, respectively. At the second stage, the assembly cools down to room temperature. The ACF is solidified and considered in the finite element analysis of the connector. The deformed shape of the assembly is shown in Fig. 4. The distribution of OLB mismatch across the span of the connector can be determined using Eqn. (2) and the result is shown in Fig. 5. It is noted that except for a few outer leads close to the free edge of the TAB, the OLB mismatch basically varies linearly across the span of the connector. The maximum mismatch of the connector is 13.37 μ m which is relatively close to the value observed in practical applications. Maximum mismatches for cases with some changes in material constants or curing parameters are also computed and the results are listed in Table 2 for comparison. It is noted that among the parameters considered, the thermal expansion coefficient of the tape may have significant effects on the OLB mismatch of the connector.

5. COMPENSATION DESIGN OF MISMATCH

Mismatch of OLBs will be inevitable if a uniform interconnection pitch is adopted in designing the TOG connection. Excessive OLB mismatch will be likely to cause early failure of the LCD panel. Therefore, methods for alleviating the adverse effects induced by OLB mismatch should be pursued. Herein, a nonuniform interconnection pitch approach is adopted to design the locations of the outer leads on the TAB and glass panel. The coordinates of the outer leads on the glass panel remain unchanged while those of the outer leads on the TAB are determined as

$$x'_{ip} = x_{ig} (1 + \zeta_g) - x_{ip} \zeta_p \quad (3)$$

where x_{ip} , x'_{ip} are coordinates of outer leads on tape before and after modification, respectively; x_{ig} are the original coordinates of the outer leads on glass panel; ζ_p , ζ_g are slopes of displacements of tape and glass panel determined at the first stage. The mismatch of the same TOG connector but with modified locations of outer leads on the TAB is also studied and the result is shown in Fig. 6. The comparison of the results in Figs. 5 and 6 shows that the adoption of the present compensation design can significantly reduce the magnitude of OLB mismatch.

6. CONCLUSIONS

Mismatch between the OLBs of the TAB and glass panel for a LCD panel has been studied using a two-dimensional finite element model. Reasonable results on OLB mismatch have been obtained. The results have also revealed that the thermal expansion coefficient of TAB may have significant effects on the OLB mismatch. A compensation method for mismatch design of TOG connections has been proposed. It has been shown that the proposed compensation method can greatly reduce the magnitude of the OLB mismatch induced in the connection. It is suggested that a three-dimensional finite element model be used in the mismatch analysis if a more accurate prediction of OLB mismatch is desired.

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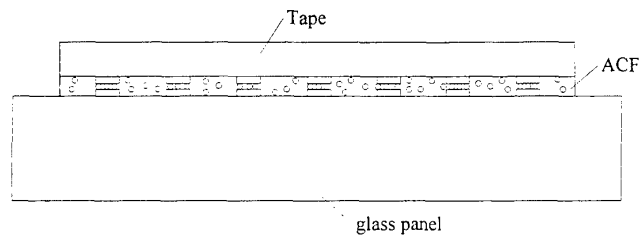
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2. H. Matsubara, H. Atarashi, K. Yamamura, N. Kakimoto, K. Naitoh, and T. Nukii, "Bare-chip face-down bonding technology using conductive particles and lightsetting adhesives:ELASTIC method," IMC 1992 Proceeding, Yokohama, pp. 81-87, 1992.
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Table 1. Material constants for components of TOG connection

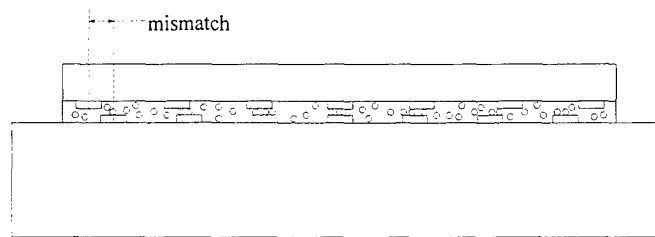
Component Constant	Tape		ACF		Glass
E(MPa)	8826		0 °C	2548	70000
			40 °C	2548	
			121 °C	1500	
			200 °C	1500	
ν	0.3		0.3		0.2
$\alpha(\times 10^{-6} / ^\circ\text{C})$	0 °C	8	0 °C	52.2	4.7
	99 °C	8	110 °C	52.2	
	100 °C	9	111 °C	177.6	
	101 °C	10	112 °C	303	
	300 °C	10	300 °C	303	

Table 2. Maximum mismatches for TOG connectors with different parameters

Modified parameter	Maximum mismatch (μm)
$\alpha_G = 3.8 \times 10^{-6} / ^\circ\text{C}$	14.43
$\alpha_P = 5 \times 10^{-6} / ^\circ\text{C}$	5.90
$T_p = 165^\circ\text{C}$	12.65



(a)



(b)

Fig. 1. 2-D view of TOG connection

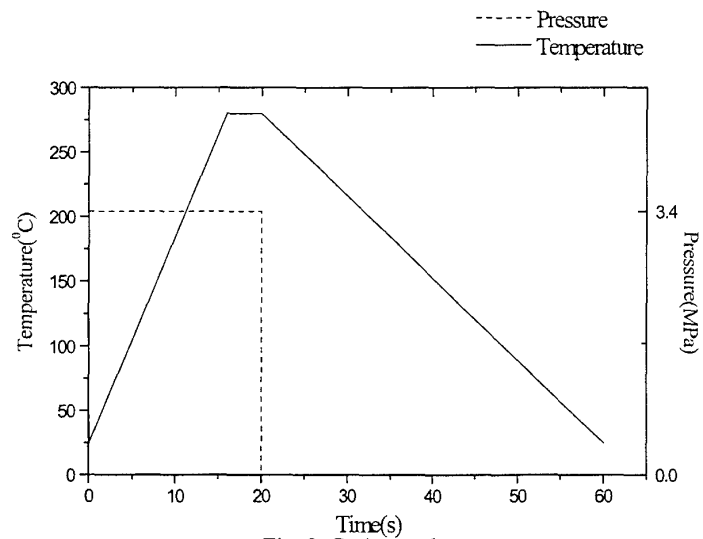


Fig. 2. Curing cycle

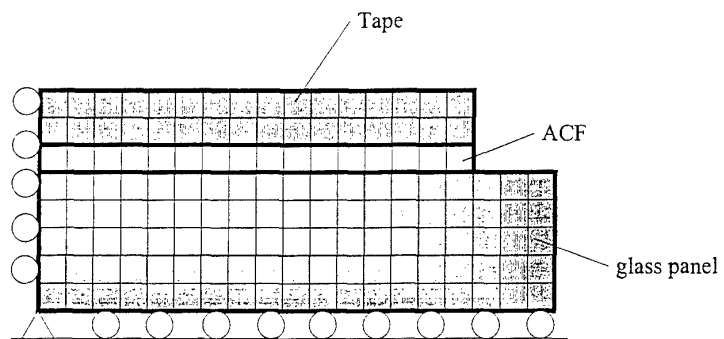


Fig. 3 Finite element model of connector

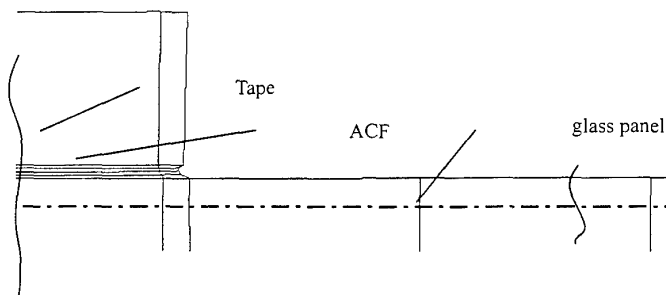


Fig. 4. Deformed shape of TOG connector

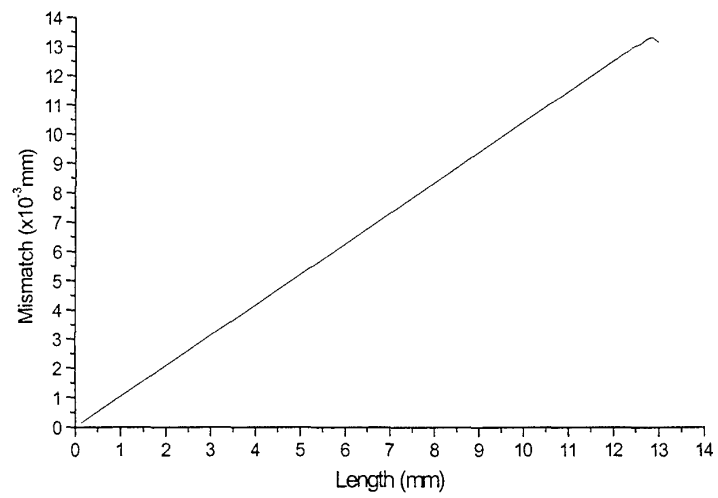


Fig. 5. Distribution of mismatch

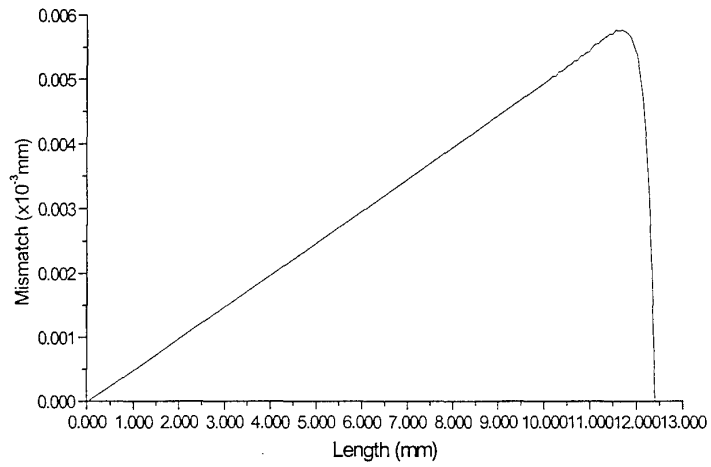


Fig. 6. Mismatch of TOG connection with compensation design

DECLARATION OF JUNE ANN MUNFORD

1. My name is June Ann Munford. I am over the age of 18, have personal knowledge of the facts set forth herein, and am competent to testify to the same.
2. I earned a Master of Library and Information Science (MLIS) from the University of Wisconsin-Milwaukee in 2009. I have over ten years of experience in the library/information science field. Beginning in 2004, I have served in various positions in the public library sector including Assistant Librarian, Youth Services Librarian and Library Director. I have attached my Curriculum Vitae as Appendix CV.
3. During my career in the library profession, I have been responsible for materials acquisition for multiple libraries. In that position, I have cataloged, purchased and processed incoming library works. That includes purchasing materials directly from vendors, recording publishing data from the material in question, creating detailed material records for library catalogs and physically preparing that material for circulation. In addition to my experience in acquisitions, I was also responsible for analyzing large collections of library materials, tailoring library records for optimal catalog

search performance and creating lending agreements between libraries during my time as a Library Director.

4. I am fully familiar with the catalog record creation process in the library sector. In preparing a material for public availability, a library catalog record describing that material would be created. These records are typically written in Machine Readable Catalog (herein referred to as “MARC”) code and contain information such as a physical description of the material, metadata from the material’s publisher, and date of library acquisition. In particular, the 008 field of the MARC record is reserved for denoting the date of creation of the library record itself. As this typically occurs during the process of preparing materials for public access, it is my experience that an item’s MARC record indicates the date of an item’s public availability.
5. Typically, in creating a MARC record, a librarian would gather various bits of metadata such as book title, publisher and subject headings among others and assign each value to a relevant numerical field. For example, a book’s physical description is tracked in field 300 while title/attribution is tracked in field 245. The 008 field of the MARC record is reserved for denoting the creation of the library record itself. As this is the only date reflecting the inclusion of said materials within the library’s collection, it is my experience

that an item's 008 field accurately indicates the date of an item's public availability.

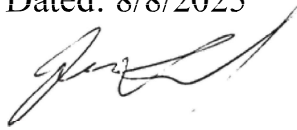
6. I have reviewed Exhibit 1014, "Mismatch Analysis of TAB-on-Glass Connection with ACF" by Wei-Fun Hou, et al as published in Display Technologies.
7. Attached hereto as Appendix HOU01 is a true and correct copy of the MARC record for Display Technologies as held by the Penn State University Library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix HOU01 accurately describes the title, publisher and ISBN number of Display Technologies. In comparing Exhibit 1014 to Appendix HOU01, it is my determination that Exhibit 1014 is a true and correct copy of "Mismatch Analysis of TAB-on-Glass Connection with ACF" by Wei-Fun Hou, et al as published in Display Technologies.
8. The 008 field of the MARC record in Appendix HOU01 indicates the date of record creation. The 008 field of Appendix HOU01 indicates the Penn State University Library first acquired Display Technologies as of December 4, 2003. Considering this information, it is my determination that Display

Technologies and therefore "Mismatch Analysis of TAB-on-Glass Connection with ACF" was made available to the public shortly after December 4, 2003.

9. I have been retained on behalf of the Petitioner to provide assistance in the above-illustrated matter in establishing the authenticity and public availability of the documents discussed in this declaration. I am being compensated for my services in this matter at the rate of \$200.00 per hour plus reasonable expenses. My statements are objective, and my compensation does not depend on the outcome of this matter.

10. I declare under penalty of perjury that the foregoing is true and correct. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made to the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: 8/8/2025

A handwritten signature in black ink, appearing to read 'June Ann Munford', written in a cursive style.

June Ann Munford



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Copyright Date

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June A. Munford
Curriculum Vitae

Education

University of Wisconsin-Milwaukee - MS, Library & Information Science, 2009
Milwaukee, WI

- Coursework included cataloging, metadata, data analysis, library systems, management strategies and collection development.
- Specialized in library advocacy, cataloging and public administration.

Grand Valley State University - BA, English Language & Literature, 2008
Allendale, MI

- Coursework included linguistics, documentation and literary analysis.
- Minor in political science with a focus in local-level economics and government.

Professional Experience

Researcher / Expert Witness, October 2017 – present
Freelance ● Pittsburgh, Pennsylvania & Grand Rapids, Michigan

- Material authentication and public accessibility determination. Declarations of authenticity and/or public accessibility provided upon research completion. Experienced with appeals and deposition process.
- Research provided on topics of public library operations, material publication history, digital database services and legacy web resources.
- Past clients include Alston & Bird, Arnold & Porter, Baker Botts, Fish & Richardson, Erise IP, Irell & Manella, O'Melveny & Myers, Perkins-Coie, Pillsbury Winthrop Shaw Pittman and Slayden Grubert Beard.

Library Director, February 2013 - March 2015
Dowagiac District Library ● Dowagiac, Michigan

- Executive administrator of the Dowagiac District Library. Located in Southwest Michigan, this library has a service area of 13,000, an annual operating budget of over \$400,000 and total assets of approximately \$1,300,000.

- Developed careful budgeting guidelines to produce a 15% surplus during the 2013-2014 & 2014-2015 fiscal years while being audited.
- Using this budget surplus, oversaw significant library investments including the purchase of property for a future building site, demolition of existing buildings and building renovation projects on the current facility.
- Led the organization and digitization of the library's archival records.
- Served as the public representative for the library, developing business relationships with local school, museum and tribal government entities.
- Developed an objective-based analysis system for measuring library services - including a full collection analysis of the library's 50,000+ circulating items and their records.

November 2010 - January 2013

Librarian & Branch Manager, Anchorage Public Library ● Anchorage, Alaska

- Headed the 2013 Anchorage Reads community reading campaign including event planning, staging public performances and creating marketing materials for mass distribution.
- Co-led the social media department of the library's marketing team, drafting social media guidelines, creating original content and instituting long-term planning via content calendars.
- Developed business relationships with The Boys & Girls Club, Anchorage School District and the US Army to establish summer reading programs for children.

June 2004 - September 2005, September 2006 - October 2013

Library Assistant, Hart Area Public Library

Hart, MI

- Responsible for verifying imported MARC records and original MARC cataloging for the local-level collection as well as the Michigan Electronic Library.
- Handled OCLC Worldcat interlibrary loan requests & fulfillment via ongoing communication with lending libraries.

Professional Involvement

Alaska Library Association - Anchorage Chapter

- Treasurer, 2012

Library Of Michigan

- Level VII Certification, 2008
- Level II Certification, 2013

Michigan Library Association Annual Conference 2014

- New Directors Conference Panel Member

Southwest Michigan Library Cooperative

- Represented the Dowagiac District Library, 2013-2015

Professional Development

Library Of Michigan Beginning Workshop, May 2008

Petoskey, MI

- Received training in cataloging, local history, collection management, children's literacy and reference service.

Public Library Association Intensive Library Management Training, October 2011

Nashville, TN

- Attended a five-day workshop focused on strategic planning, staff management, statistical analysis, collections and cataloging theory.

Alaska Library Association Annual Conference 2012 - Fairbanks, February 2012

Fairbanks, AK

- Attended seminars on EBSCO advanced search methods, budgeting, cataloging, database usage and marketing.

Depositions

2019 ● Fish & Richardson

Apple v. Qualcomm (Case No. IPR2018-001281, 39521-00421IP, IPR2018-01282 and 39521-00421IP2)

2019 ● Erise IP

Implicit, LLC v. Netscout Systems, Inc (Case No. 2:18-cv-53-JRG)

2019 ● Perkins-Coie

Adobe Inc. v. RAH Color Technologies LLC (Case No. IPR2019-00627, IPR2019-00628, IPR2019-00629 and IPR2019-00646)

2020 ● O'Melveny & Myers

Maxell, Ltd. v. Apple Inc. (Case No. 5:19-cv-00036-RWS)

2021 ● Pillsbury Winthrop Shaw Pittman LLP

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2022 ● Perkins-Coie

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Purdue University v. Wolfsped (Case No. 1:21-CV-840)

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- Ericsson

v. Collision Communications (Case No. IPR2022-01233)

- Nokia

v. Neptune Subsea, Xtera (Case No. 1:17-cv-01876)

- Universal Electronics Inc

v. Roku Inc (Case No. IPR2022-00818)

Alavi & Anaipakos PLLC

- Stingray Group Inc. and Stingray Music USA, Inc.

v. Edwin A. Hernandez-Mondragon and Egla Corp. (Case No. 1:24-cv-21226-RAR)

Arnold & Porter

- Ivantis

v. Glaukos (Case No. 8:18-cv-00620)

- Samsung

v. Jawbone (Case No. 2:21-cv-00186)

Benesch Friedlander Coplan & Aronoff

- Voyis

v. Cathx (Case No. 5:21-cv-00077-RWS)

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