ARTICLE IN PRESS

Engineering Fracture Mechanics xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

On the mechanics of laser peeling for ultra-thin glasses

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ARTICLE INFO

Article history:
Received 19 January 2016
Received in revised form 29 May 2016
Accepted 21 June 2016
Available online xxxx

Keywords:
Laser
Phase change
Brittle fracture
Defect removal

ABSTRACT

Laser peeling is a surface defect removal process involving irradiating laser pulses on edges of ultra-thin glasses. Mechanical- or laser-cutting induced edge defects on glass edges are removed by peeling off a thin layer containing the cutting defects. The new edge-surfaces of the glasses are defect-free and much less prone to cracking failure. In this paper the mechanism of this material removal process is investigated. From experimental observations and theoretical calculations, it is shown that the laser glass peeling is a brittle fracture process driven by residual stress associated to glass surface phase change phenomenon, as opposed to the typical laser ablation material removal. A quantitative fracture mechanics model that simulates the laser induced glass peeling process is also presented.

1. Introduction

Ultra-thin glasses of thicknesses lesser than 200 μm have been targeted as the cover material for flat panel displays used from smartphones to televisions. The scratch resistance of these glasses is typically enhanced chemically by doping large-volume ions to introduce residual compressive stresses around glass surfaces and accompanying residual tensile stress in the interior of the glass. These strengthened glasses, while are much improved against mechanical loading applied on their surfaces, are still prone to shattering when forces are exerted on the periphery of the glass. These edge-originated cracks can be attributed to glassing-cutting induced edge and corner defects, the growth of which are enhanced by the chemical-doping related residual tensile stress. A direct and effective approach for mitigating the periphery-cracking induced glass failure is to remove the preexisting defects by mechanically polishing the periphery of the ultra-thin glass. Implementation of the periphery polishing process for small glass components used in hand-held electronics is relatively straightforward, but would be very complicated for large panels and glass rolls in roll-to-roll (R2R) processing [1] because of the ultra-thin glass support issues.

As an alternative to the mechanical polishing process, a novel technique for removing the micro-defects on the periphery of ultra-thin glasses was recently proposed [2]. In this approach, a CO_2 laser with a suitable power is irradiated on the edge-surface of the ultra-thin glass, as shown in Fig. 1. The laser irradiation leads to a spontaneous peeling of a thin glass layer from the edge of the glass. As a result of the peeling process, the preexisting micro-defects are removed from the edge, the new edge of the glass becomes crack-free, and the strength of the ultra-thin glass is substantially enhanced. An example of the edge-surface quality improvement of a 100 μm-thick borosilicate glass resulting from the laser peeling process is

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http://dx.doi.org/10.1016/j.engfracmech.2016.06.014
0013-7944/

Please cite this article in press as: Chiu T-C et al. On the mechanics of laser peeling for ultra-thin glasses. Engng Fract Mech (2016), http://dx.doi.org/10.1016/j.engfracmech.2016.06.014

Nomenclature

E	Young's modulus of the glass
$F_\xi^k, F_\eta^k (k = i, j)$	ξ- and η-direction forces at nodal point k
f	laser irradiation frequency
G	strain energy release rate
G_I, G_{II}, G_{I-II}	crack closure integrals
G_s	steady-state strain energy release rate
h	thickness of peeled glass strip
h_s	steady-state depth of the peeling crack
K_I, K_{II}	mode-I and -II stress intensity factors
r, θ	polar coordinates with origin at the crack tip
t	thickness of the laser-affected surface layer
t_{ij} $(i, j = 1, 2)$	constants used in crack closure integral calculations
u^k, v^k $(k = l1, l2, m1, m2)$	ξ- and η-direction displacements at nodal point k
W	average emitting power of laser
$\bar{z}$	neutral axis height
Δ	crack tip element dimension
ε^{th}	residual strain in laser-affected glass surface layer
ξ, η	local coordinates for the crack-tip finite elements
ρ	radius of curvature of the peeled glass strip
σ	normal stress in the peeled glass strip
ψ	phase angle

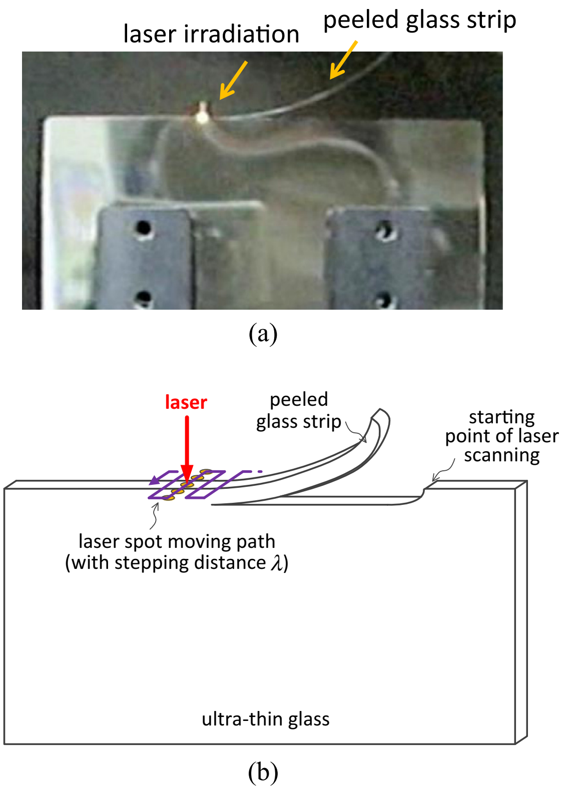

Fig. 1. The laser-peeling process, (a) a snapshot of the glass peeling, (b) schematic of the process.