D4 Non-Destructive Test Method for Forensic Evaluation of Motorcycle Helmet Shell Failure Mechanism and Resulting Safety Deficiency Causing Fatal Head Injury

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After attending this presentation, attendees will understand how to apply a method for non-destructive analysis for scientific evaluation of potential manufacturing flaws in certified motorcycle helmet shell structural failures that result in severe head injury.

This presentation will impact the forensic science community by providing a non-destructive, evidence preserving method for evaluation of potential manufacturing defects in motorcycle helmet exterior shell failures associated with severe head injuries.

Concussion and severe head injuries sustained by motorcycle-helmeted riders using Snell and Department Of Transportation (DOT) -certified helmets are sometimes caused by manufacturing defects in the composites and plastic materials typically used in the fabrication of the critical outer protective helmet shells. The structural integrity of the outer shells is necessary to fully engage and spread the head/helmet outer surface contact impact forces over as large of a surface area and volume of the inner energy-absorbing liner as possible to minimize high-intensity focal impact forces that would otherwise transfer to localized regions of the skull/brain system and contribute to a more severe loading; however, if the shell integrity and containment load-distribution-function capability fails when the helmeted head strikes the pavement, such as when a sudden crack propagation failure in the shell occurs due to a manufacturing deficiency, the impact loads to the inner liner and head and are then concentrated on a smaller surface area, with concomitant higher focal impact that often results in severe-to-fatal load levels in the skull-brain system.

The two most common motorcycle helmet shell construction materials are the less expensive and easily fabricated injection molded thermoplastics shell, such as the polycarbonates types, and the more expensive fiber-resin laminate lay-up composite shells. Crack propagation failures in the polycarbonate helmet shell designs are typically caused by the formation of high-stress concentration impurity sites that result from mixing the more uniform and stronger virgin polycarbonate plastic material with older, used, reground plastic material obtained from the reuse of previously molded and rejected shells, which save on material-fabrication costs. With regard to the fiber-resin laminated composite shells, "resin-starved" laminates cause typical manufacturing flaws and shell stress concentration and load distribution failures. In addition, irregular laminate ply-lay-up and overlap coverage, coupled with large material thickness variations, also result in shell failure zones. The side-by-side figure below illustrates two fatal accident helmet cases in which shell fracture occurred and allowed localized loading to the skull-brain system. The left photo shows a fiber-resin composite shell failure and the right photo illustrates a polycarbonate molded shell failure.

Early research by Hodgson and Saczalski have addressed helmet performance and design issues related to the biomechanics of head-helmet loadings, and associated injury risk effects on humans, by using both analytical-numerical analysis methods and destructive impact testing of helmet systems and components; however, in order to preserve and maintain evidence in the "as-found" condition, which is needed for forensic reasons, a damaged motorcycle-accident helmet that exhibits crack failures in the outer shell structure requires the use of Non-Destructive Evaluation (NDE) techniques as well as dynamic-impact testing of exemplar helmets.[1,2] This study presents an NDE approach for identifying potential manufacturing flaws in motorcycle helmet shell structures made of both fiber-resin composites and plastic molded shells in which shell fractures resulted in severe head injuries.

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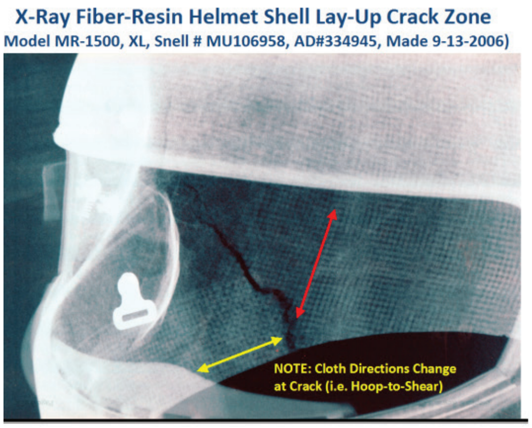
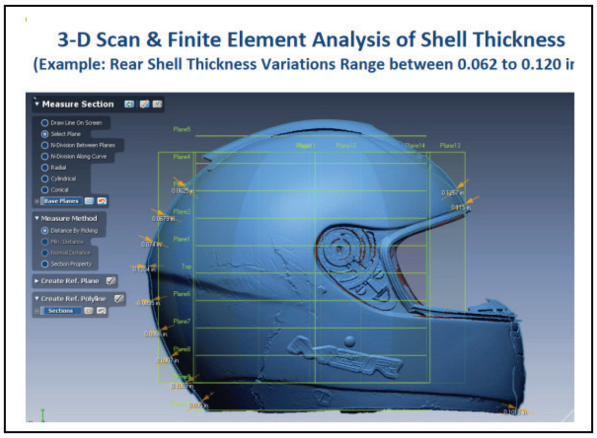
The NDE method used in these helmet-failure studies involves three stages. First, the fracture sites on the outer and inner surface of the shells are carefully examined by using macro-photographic evaluation, both before any helmet disassembly is performed and after disassembly, in order to more carefully examine the damage zones of the crack region of the shell, as well as to examine the mating surface of the inner energy-absorbing liner materials. This stage of the examination documents "close-up" visual evidence of impurities in the plastic molded material shells and also reveals irregularities in fiber-resin fracture patterns in composite shell structures, often associated with "resin-starvation" or improper cure of the resin matrix chemical bonding. Second, the helmet shell materials are examined for zones of flaws through the thickness of the material by using ultra-sound scans and X-rays to more carefully examine irregularities within the shell materials. Third, the accident shell structures are digitized with 3D scanning devices to enable accurate measurements of shell thickness variations at and around the regions of the shell fracture. Finally, if located, exemplar accident helmets are tested to evaluate several of the observed factors, including duplication of failures and consistencies of shell flaws as well as comparison with non-defective designs. The figure below illustrates an X-ray of the fiber-resin shell shown above and a "finite-element" thickness model.





The photo below shows the results from a drop-impact test run on an exemplar of the polycarbonate helmet shown on the right side in the first photo above. This test duplicated the accident helmet failure when tested according to the National Highway Traffic Safety Administration (NHTSA) helmet standard FMVSS-218. As noted above, the blending of recycled plastics with virgin materials in the molding of plastic helmet shells will likely lead to inclusions of impurities and stress concentration failure sites. The exemplar tested plastic and fiber-resin composite shell helmets allow for more detailed material defect testing in the forms of Differential Scanning Calorimetry (DSC) and Fourier Transform Infrared Spectroscopy (FTIR).

The NDE and exemplar helmet testing methodology applied in this study provides an efficient and economical means for verifying dangerous manufacturing defects in DOT- and Snell-certified helmet designs without the need for destructive testing on the actual accident helmet in evidence. Finally, it should be noted that evidence of a shell fracture does not necessarily verify a manufacturing defect unless a procedure such as that employed in this study is conducted.

Reference(s):

1. Communication from Voigt R. Hodgson, Ph.D., Director of the Gurdjian-Lissner Biomechanics Laboratory at Wayne State University, to Kenneth J. Saczalski, Ph.D., Office of Naval Research, June 13, 1975.
2. Saczalski K.J., States J.D., Wagar I.J., Richardson E.Q. A Critical assessment of the Use of Non-Human responding Surrogates for Safety System Evaluation, *Twentieth Stapp Car Crash Conference Proceedings*, SAE paper 760805, 1976.

Helmet Defects, Head Injury, NDE Evaluation