THE FIFTH ESTATE
IIT Madras Student Media Body

presents

IMMERSE

IIT Madras Science Magazine

sponsored by

COMMUNICATION

COMPUTING

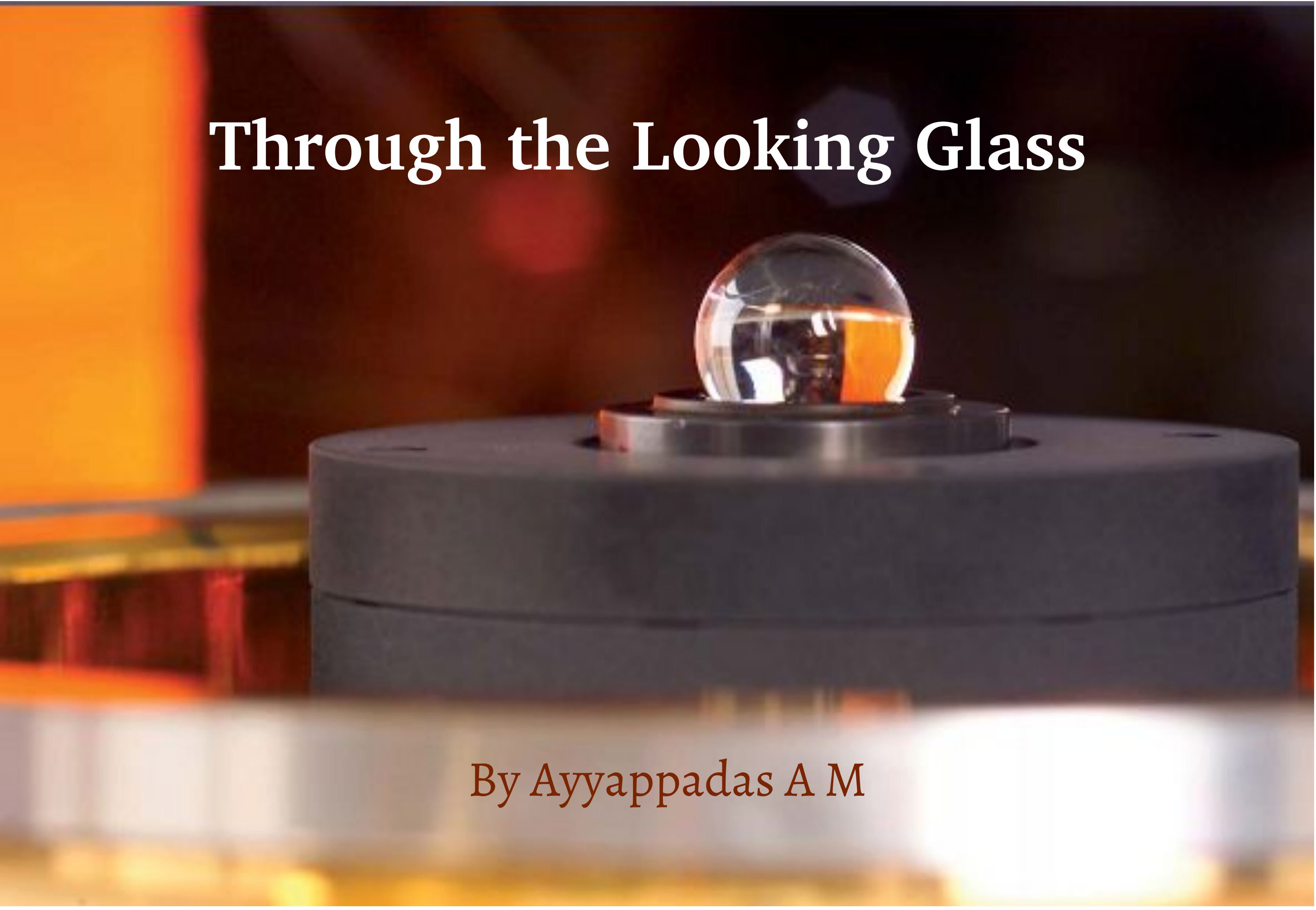
ECONOMICS

HEALTH

ENERGY

DEFENSE

MATERIALS



Through the Looking Glass

By Ayyappadas A M

How digital photoelasticity research empowers the mobile revolution

Imagine a research group consisting of mechanical engineering graduates and headed by a world renowned expert in the subject area of experimental stress analysis. Could they be silently empowering the mobile, IT revolution and technology convergence, by doing engineering research from their subject domains? This is the story about such a technology bridge, made possible through furthering the understanding of science and its applications. Their story often goes unsung, although their work shines out from the smiles you capture through Instagram or the high quality videos played from your BluRay DVD. We will see how diverse technologies such as image processing, numerical computing, and stress analysis have come together to help the mass production of optical devices.

Let there be light

The history of science and technology is replete with examples of cross-disciplinary application of scientific principles which have accelerated technological developments. In this case the common thread happened to be light. In fact, it is interesting to note that the phenomena which finally came to draw the demarcation line between classical and modern physics also links different disciplines. The digital photoelasticity research group, headed by Prof. K Ramesh from the Department of Applied Mechanics, IIT Madras, are the people behind this impressive feat. Their journey began through the Indo-European Union project under FP7 initiative known as SimuGlass. They started off with a straight forward, though not necessarily simple, objective - to validate the results from a finite element simulation

Dr. K Ramesh is currently a professor at the Department of Applied Mechanics, IIT Madras. He was its Chairman during (2005-2009) and formerly a professor at the Department of Mechanical Engineering, IIT Kanpur. In recognition of his significant contributions in photoelastic coatings, the F. Zandman award was conferred on him by The International Society of Experimental Mechanics in 2012. He is a Fellow of the Indian National Academy of Engineering (2006).

tool developed for predicting the residual stresses produced in optical lenses during the manufacturing process known as precision glass moulding. The challenges faced during their research made them rise to the occasion by unravelling important insights about the physics behind the phenomena of residual stress in moulded lens. Their work has the potential to make the production of optical lenses much more efficient, adding to the mobile revolution.

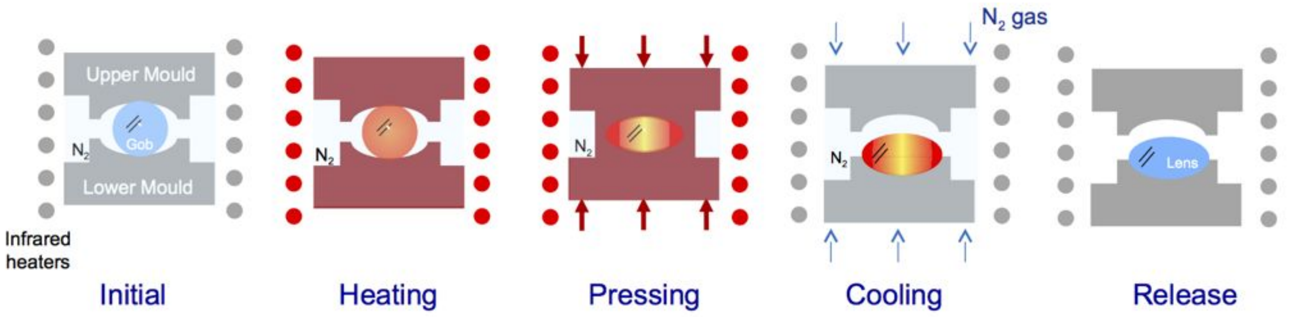
Prof. K Ramesh has been involved with research in digital photoelasticity for more than two decades. He has produced milestone papers in the subject area, and is recognised as an authority in his field. Therefore, it is not surprising that he is a key collaborator in a high impact industry project involving European and Indian institutes and industrial partners. The European partners of the SimuGlass project consisted of two academic research institutes - Fraunhofer Institute for Production Technology IPT and Centre de Recherches de l'Industrie Belge de la Ceramique and two industry partners – Kaleido Technology and EcoGlass, while the Indian partners include Central Glass and Ceramic Research Institute (CGCRI), Indian Institute of Technology Madras (IITM), Indian Institute of Technology Delhi (IITD) and Bharat Electronics Limited (industry partner). The Indian wing of the project was headed by Dr. Dipayan Sanyal from CGCRI. The stated aim of the project was to enhance the understanding of the precision glass moulding process and to increase the quality of the process by developing an integrated Finite Element tool. It was also envisaged that through the project "the state-of-the-art of manufacturing in India and parts of Europe, which follows the grinding and polishing route, will be replaced with the advanced precision press forming route, especially for manufacturing the advanced optical elements."

> *Their work has the potential to make the production of optical lenses much more efficient, adding to the mobile revolution.*

Precision Glass Moulding

As a collaborating institute, the role of IIT Madras was initially limited to the measurement of residual stresses in optical lens using methods from photoelasticity and validation of the finite element method tool for process optimisation. Tarkes Dora P and Vivek Ramakrishnan, PhD students working with Prof. K Ramesh at the Digital Photoelasticity Lab, Department of Applied Mechanics, have been involved with the project from the time they joined the Indian Institute of Technology Madras. Tarkes, whose PhD work is almost exclusively based on the research done under the auspices of the project, had this to say: "you know, it was like solving a long puzzle, by taking one challenge after another in diverse fields, until a larger picture emerged."

So what is precision glass moulding and why is it relevant? Tarkes replies, "The conventional manufacturing process of optical lenses is a multi-step and highly time consuming process. And is that all? "No", Tarkes continues, "The digital revolution has unleashed a new market for such precision glasses. In today's world, everyone

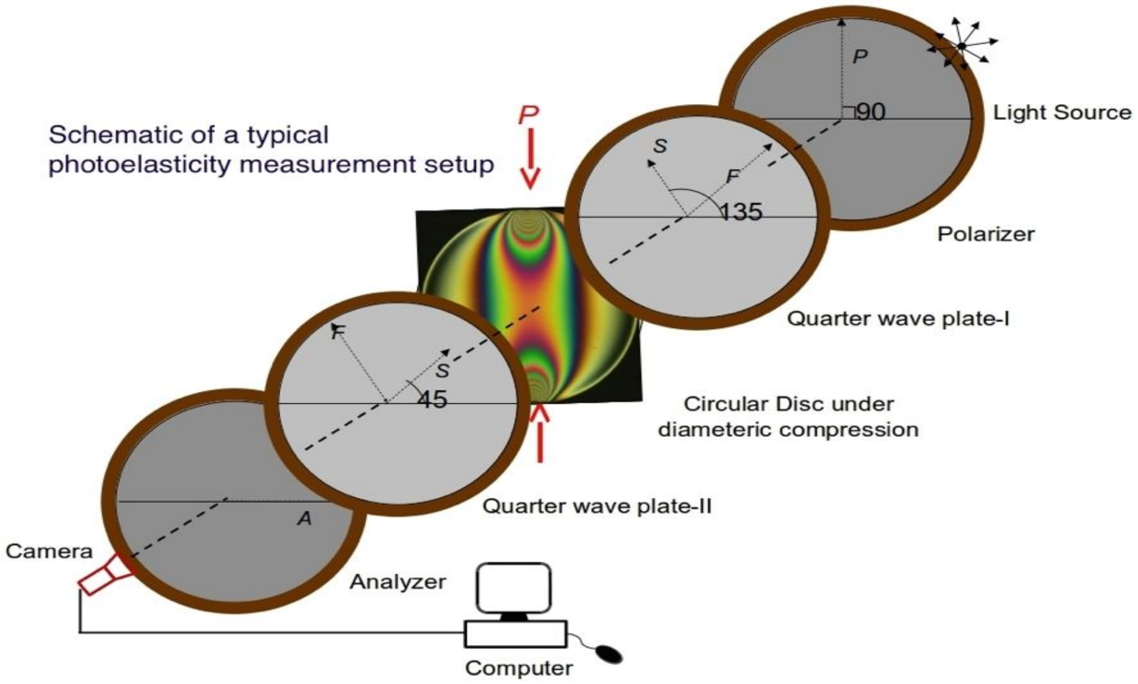


Steps involved in Precision Glass Moulding

with a mobile phone is an amateur photographer. The convergence has come to the level that one or more optical devices have become standard in most consumer electronics, and particularly in the communication devices. The demand for these devices has been exponential in the past decade. This has created a situation where dependency on conventional production process involving grinding and polishing has become virtually impossible.”

> *It was like solving a long puzzle, by taking one challenge after another in diverse fields, until a larger picture emerged.*

Precision glass moulding involves five steps as shown in the figure. First the cold glass blank with a defined geometry, called gob, is loaded into the mould. The oxygen is removed from the working area, followed by nitrogen filling. The whole system is then heated. The variables that affect the quality of the product - temperature and the force applied come after this stage. The glass is heated to a point slightly above what is known as glass transition temperature. Glass transition temperature is the temperature at which glass changes from a hard and relatively brittle state into a molten or rubber-like state. The value of this depends on the composition of the glass. Optical glasses have low transition temperatures, typically between 400°C and 550°C. The mould quality degrades due to wear and tear if glasses with higher transition temperature (550-600°C) are used.


Schematic of a typical photoelasticity measurement setup

After heating, the glass gob is pressed to the desired shape. The whole assembly of lens and mould is cooled to room temperature. The final lens can be directly used for the desired application.

Residual stress is the internal stress distribution locked into a material. These stresses are present even after all external loading forces have been removed. Residual stresses are developed in the lens during the cooling. In conventional method, the glass lens is annealed, (a heat process that involves slow cooling) intermediately. This minimises the residual stresses. There is also the issue of shape deviation in the lens. Repeated trial and error experimentation, in order to minimise the residual stresses and shape deviation is prohibitively expensive, given that a large cost is involved in the manufacturing of the moulding tools. Very few companies such as Aixtooling GmbH produce the ultra-precise high quality moulding tools. Thus, numerical computation with finite element method has become the obvious choice to get the optimised shape of the mould and for selection of thermal cycles.

Manufacturing meets photoelasticity

As soon as the team at IIT Madras took a plunge into the problem, they encountered several hurdles. It was one thing to do photoelastic measurements with plastic materials. Optical glasses were, however, a totally different territory. The fringe widths to be measured were in microns as compared to millimetres, and the requirement of precision was also higher.

Glass is a weakly birefringent material. The fringe order usually observed is less than one. Measurement of birefringence in glass up to 2 nanometers is possible using an instrument called automatic polariscope (for e.g.: manufactured by M/s GlassStress Ltd., Estonia which uses phase shifting technique). There were 'low' and 'high' photoelastic constant glasses, whose stresses are to be measured. The accuracy of measurement suffers when the range of values go from one extreme to the other, while using the same process. They overcame the precision related hurdles by devising two experimentation techniques. The team proposed a new experimental technique using Carrier Fringe Method for photoelastic calibration of glass for higher values of photoelastic constants. Also for relatively low photoelastic constant materials, a new experimental method involving phase shifting technique was devised.

The Finite Element Method based Process Optimisation

The accuracy of the final product is of utmost importance as far as precision moulding is concerned. The conventional method for obtaining high accuracy has been based on trial and error, and domain expertise of the process engineer. The SimuGlass envisaged at changing this paradigm. And indeed, they found a breakthrough. A simpler method to obtain the optimised design of the mould with submicron-form accuracy (shape deviation < 1 micron) was proposed by the IITD and IITM teams in 2014.

Bench-Top Precision Glass Moulding Apparatus
Source: PGPL, Isfahan University of Technology

Finite Element scheme for simulation and analysis of the moulding process involves several other challenges. The thermo-mechanics of glass involves two aspects - viscoelasticity and structural relaxation. Viscoelasticity models are available in commercial software packages like ABAQUS. The structural relaxation has to deal with the nonlinear thermal expansion. There was no standard method

Photoelasticity

Photoelasticity is an experimental method to determine the stress distribution in a material. It is advantageous because of its ability to give a fairly accurate picture of stress distribution, even around abrupt discontinuities in materials. A typical photoelastic measurement setup consists of a light source, a polariscope, a transparent material which is to be analysed, and an image capturing device. First described by the Scottish physicist David Brewster, the method has come a long way to become a very important tool in engineering and research.

available in commercial packages for solving this problem with sufficient accuracy. Tarkes from the IIT Madras team in collaboration with IITD Team developed the code for solving the structural relaxation problem.

At the beginning of the project the use of digital photoelasticity was only envisaged as a validation tool. But soon this was to change. The key issue was that the physics of heat transfer involved in the moulding process was not well understood. This is to say that the heat transfer mechanism between the mould and glass, the glass and the surrounding N_2 atmosphere should be known for sure, if the numerical computation results were to be reliable. The experiments were conducted in the facility at Fraunhofer Institute for Production Technology, Germany. When the results from the finite element model were compared, it was evident that the assumptions made about the heat transfer mechanism for glass and N_2 interaction was far from accurate. This prompted them to relook the problem from the heat transfer point of view. They did a computational fluid dynamics simulation of the cooling stage of the moulding process. This revealed that the mechanism was not likely convection, as it was believed or assumed previously. Tarkes analysed the temperature measurement data and paved the way to account the actual heat transfer mechanism. They ended up using digital photoelasticity values as a significant input parameter by which they are able to predict more accurate values to be used in the finite simulation to account this heat transfer mechanism.

The Bottom Line

In business everything comes down to a bottom line. I asked the team how their work fits into the larger frame. And this is what they had to say: “the accuracy of the simulation has been of the order of 50-60%. The work done by our group has potentially improved this to 70-80%. Most importantly, the science of the process is now better understood. The discovery that the cooling of the lens in the precision glass moulding does not happen through convection is a breakthrough. An increment of accuracy by 20% is one significant step towards massive improvement in the mass production levels.” In short, thanks to such collaborations, all of us are able to get higher resolution cameras in our mobiles. More importantly, this will go a long way in improving the quality of optical lenses, which has a direct impact on clinical fields. ■

Meet the Author

Ayyappadas A M is a PhD scholar working in Fluid Dynamics, at the Department of Applied Mechanics. Apart from the science-y stuff he does, by way of research and personal interest, he is an avid reader of philosophy and history. Infrequent blogger, but *mostly harmless*.