

# Chapter 11

## Deformation Measurement within a Volume of Translucent Yield Stress Material Using Digital Image Correlation

A. McGhee and P. Ifju

**Abstract** This paper introduces a method of determining in-plane deformation of a translucent yield stress material (YSM) at any depth using digital image correlation. A 2D plane of uniquely shaped speckles are introduced to a volume of the YSM using a 3D printing technique. A cylindrical object, is dragged through the 2D plane at four different speeds each with four different diameters. The displacements caused by the cylinder were found and analyzed.

**Keywords** 3D printing • Carbomer 940 • Digital image correlation • Soft matter • Yield stress material

### 11.1 Introduction

A robust method of measuring the in-plane displacements within a translucent yield stress material (YSM) has been developed. Although the ability to measure deformation within a yield stress material is nothing new, the techniques employed previously have many limitations which restrict the type of analysis that can be done. Previous experiments have used glass beads suspended in a volume of the YSM which are illuminated with a laser sheet which allow for particle tracking of the glass beads. Since the glass beads are all shaped the same, the displacement of these beads can only be detected if the displacement between an image pair is very low [1]. Large displacements can be measured with this method, but requires many correlations between sequential image pairs to be correlated and summed together; where each correlation introduces some amount of error which would stack up throughout the summation. Our method, however, utilizes uniquely shaped speckles which allow for large scale displacements to be measured directly and with low error. The methods described here can be used with all types of yield stress materials as long as the speckle pattern can be imaged.

The yield stress material used in this experiment is called Carbomer 940 which when introduced to water and a base such as NaOH creates a volume of individually swollen microgel particles with a cross section of about 10  $\mu\text{m}$ . These microgel particles jam together to give the gel material properties of a solid, yet the ability of these particles to shear due to some stress give the gel fluid like properties as well. The amount of stress needed for the particles to shear is called the yield stress, and this yield stress is highly dependent on the rate of the shear event. Rheological analysis show that the Herschel-Bulkley model provide the best fit for the shear rate versus the yield stress [2].

### 11.2 Experimental Method

Digital image correlation (DIC) usually measures the deformation of a surface, but we are interested in the in-plane displacement within a medium. To do this, uniquely shaped speckles made of tinted polyethylene glycol (PEG) are printed into a volume of YSM using a 3D printer with an injection needle attachment (Fig. 11.1). Above the speckle pattern a layer of white paint premixed with the YSM is printed and acts as a background. Cylinders of four different diameters, 0.41, 0.81, 1.27, and 1.82 are moved through the speckle plane at speeds of 0.01, 0.1, 1, and 10 mm/s with the cylinder tip far from the speckle plane.

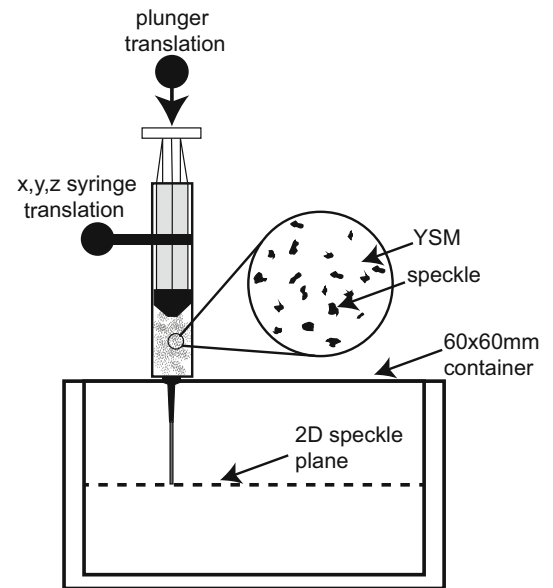
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**Fig. 11.1** 3D printing of speckle plane with syringe and 3D printer into container



A  $60 \times 60 \times 40$  mm plastic container, filled with YSM, is large enough for boundary effects to be considered negligible. Since the boundary does not interact with the needle, we can make an infinite plane assumption.

A 3D printer is used to insert a 2D plane of polymeric speckles, as well as a white background layer. The same 3D printer used to insert the 2D plane of speckles was used to control the cylinders displacement through the medium. The specimen to be tested was placed on a transparent acrylic surface, and a camera was mounted underneath. A sequence of images were taken as the cylinder is dragged through. These images were then processed using Ncorr (an open source 2D-DIC application for MATLAB) [3]. Using the cylinders location in each deformed image as a reference point, an area around the cylinder was extracted from each deformation measurement. Since the cylinder was at steady state and deforming an infinite plane, all deformation measurements should be the same. By taking many deformation measurements along the path, statistical measurements can be made.

### 11.3 Results

After analysis of each cylinder and speed combination we obtained the  $u$  ( $x$ -direction) and  $v$  ( $y$ -direction) displacements as well as a magnitude of displacement plot as can be seen for the 0.81 mm diameter cylinder at 0.1 mm/s in Fig. 11.2. To visualize the effect of velocity and diameter on the displacement away from the cylinder, a plot which shows all speed and diameter combinations is presented in Fig. 11.3. By keeping the scale of the deformation constant in each image, a direct comparison of the effect of velocity and diameter can be seen. By dragging the cylinder back to its initial position and then analyzing the reference image to the total deformation the regions of plastic and elastic deformation can be visualized.

### 11.4 Discussion

The results show high-quality results which measure displacements on the order of  $10 \mu\text{m}$  with a deviation of approximately  $2 \mu\text{m}$ . By increasing camera resolution and frame rate this technique can easily produce higher quality results than those shown. The technique can also be easily modified to measure out-of-plane distortions by introducing a second camera and a 3D correlation processor. Each deformation field in Figs. 11.2 and 11.3.

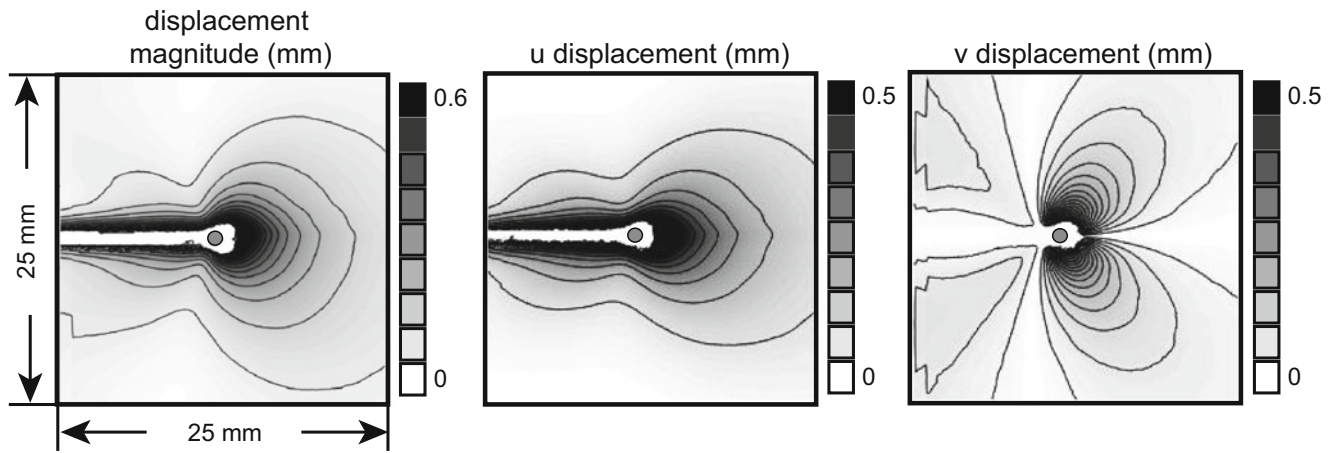


Fig. 11.2 The resulting deformation fields for the 0.81 mm diameter cylinder at 0.1 mm/s

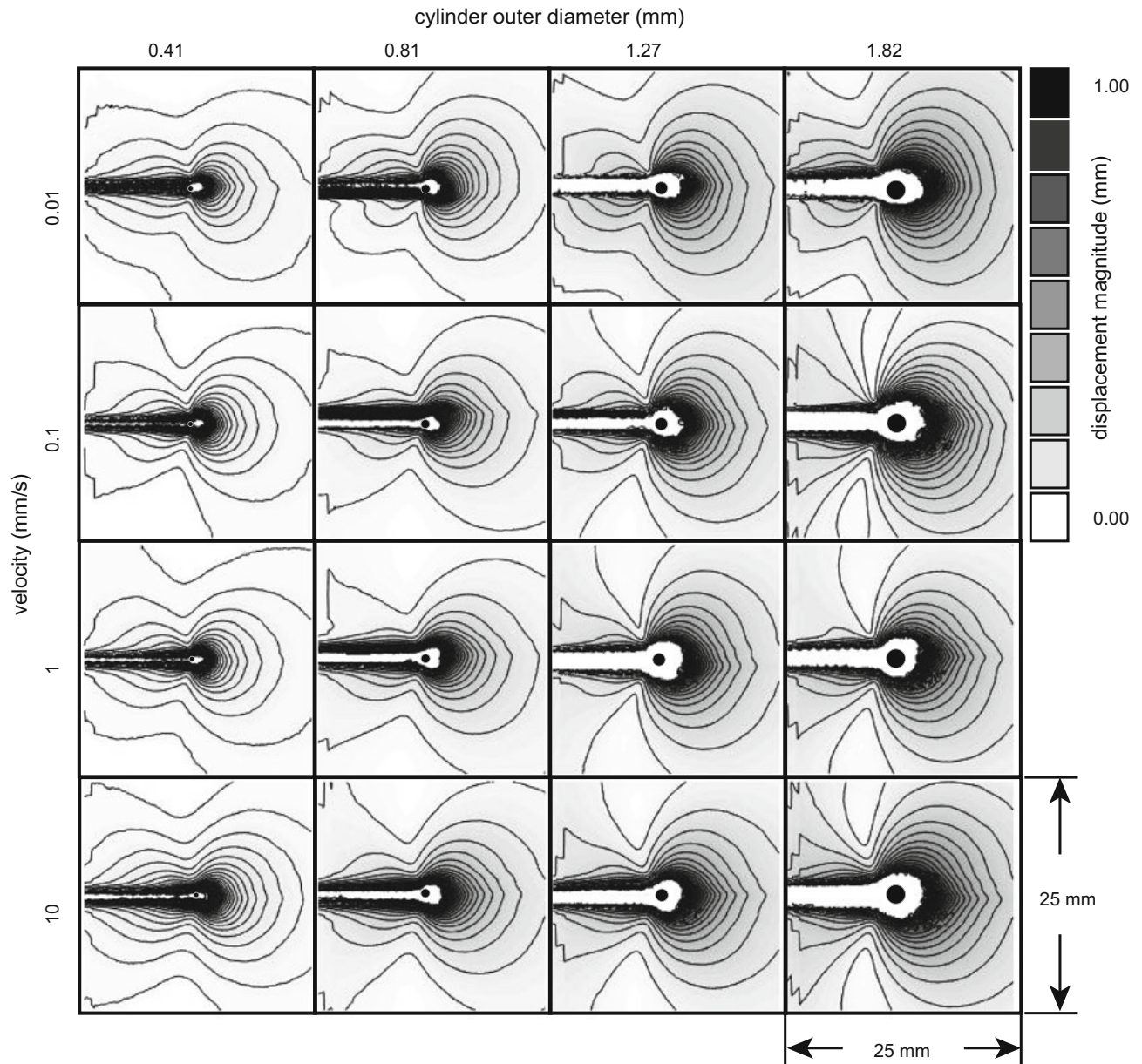


Fig. 11.3 All cylinder diameters and speed combos plotted with the same scale with contour lines

## 11.5 Conclusion

We have introduced a method of determining in-plane deformation of a translucent YSM) at any depth using digital image correlation by 3D printing a 2D plane of uniquely shaped speckles. By deforming the YSM with a cylindrical object at four different speeds each with four different diameters we were able to measure the subtle differences in the full field displacement due to changing kinematic and geometric conditions.

## References

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