

# 201 Complete In-Process Stress Strain Measurement of the Free-Stretch-Blow Process for Polymer Containers

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**Abstract.** This paper is concerned with measuring the large finite stretch ratios (<450%) observed in the stretch-blow moulding (SBM) process, primarily that of thin-walled polyethylene terephthalate (PET) containers. A novel method of measuring the hoop and axial strain levels during the formation process is proposed when the initial preform is stretched and inflated. By removing the mould and performing free-stretch-blow tests, stereoscopic high-speed cameras capture the entire rapid inflation process. Post-process digital image correlation (DIC) then allows for a full-field strain map to be obtained. Along with integral process instrumentation to quantify the stretch-rod and pressure loads applied, a complete 'fingerprint' of the process is presented. This fingerprint is dependent on both the preform material and the process parameters and by standardising this analysis, a novel characterisation approach is now accessible for the ISBM process. We call this characterisation process INDICATE.

## Introduction

Understanding how the preform deforms into the proposed bottle design is the key to a successful product, with regards to both performance and material saving; if the process can be optimised then a lighter, stronger container is achievable. Previous attempts to understand the material behaviour at conditions similar to the ISBM process have usually used some form of dedicated testing analysis i.e. biaxial stretching [ref]. This relies on dedicated polymer specimens being produced and idealised testing scenarios. INDICATE offers a novel approach to capturing the material behaviour by assessing the subject preform directly. A dedicated INDICATE instrument has now been developed by Queen's University Belfast through a €1M funded project.

## Methodology

The INDICATE instrument can analyse a multitude of preform diameters (20-50mm), any preform length and any material. The pre-patterned preform is loaded into INDICATE where a 6-axis Universal Robot transfers it to a silicone oil bath. The preform is heated above T<sub>g</sub> to the required temperature where it is then transferred to the blowing station. The preform is then stretch-blown in view of the stereoscopic cameras where the high-speed images are recorded along with the internal cavity pressure and stretch-rod reaction force using the instrumented stretch-rod [ref]. The analyse is only concerned with pre-blow pressures, the final blow pressure is not introduced. The instrument is also capable of applying a flow rate variable through a flow restrictor and blow timing i.e. the time the pressure is activated relative to the stretch-rod position. The output data is then post-processed to provide the material behaviour directly from the preform; the stress strain response is derived from the loads (pressure, force) and the deformation (strain map).

**Table 1** INDICATE Specification



Preform neck diameter [mm]	20-50
Preform temperature range [°C]	95-115
Stretch-rod speed [m/s]	<2.5
Blowing pressure	<12bar
High speed cameras	Photron FASTCAM MINI UX50
Lens	Nikon Nikkor AF 20mm f/2.8
Frame rate	<2000fps
Focal length [mm]	600 (approx.)
Stereoscopic angle [°]	35
DIC software	VIC3D
Correlation technique	Standard

**Fig. 1** INDICATE Instrument

The strain map determined from the outer preform surface is then converted to the mid-plane of the preform thickness and the hoop and axial stresses are calculated at any given point on the preform surface assuming membrane theory [ref]

$$\frac{\sigma_{hoop}}{R_1} + \frac{\sigma_{axial}}{R_2} = \frac{P}{t} \text{ Eq. 1}$$

Where  $\sigma_{hoop}$  and  $R_1$  are the circumferential stress and radius of curvature respectively,  $\sigma_{axial}$  and  $R_2$  are the meridional stress and radius of curvature respectively,  $P$  is the internal pressure and  $t$  is the wall thickness. The hoop and axial stresses may then be calculated based on the respective loads and resulting geometry.

$$\sigma_{axial} = \frac{1}{2t \sin\theta} \left( rP + \frac{F}{\pi r} \right) \text{Eq. 2}$$

$$\sigma_{hoop} = \frac{r}{\sin\theta} \left( \frac{P}{t} - \frac{\sigma_{axial}}{R_2} \right) \text{Eq. 3}$$

Where  $r$  is the horizontal radius,  $F$  is the reaction force, and  $\theta$  is the tangential angle relative to the preform surface.

## Results & Discussion

Several trials were performed examining the effect of preform and material specification on the blowing behaviour. Three factors were analysed to demonstrate the efficacy of INDICATE, with two levels for each factor, Table 2.

**Table 2** Experimental analysis overview

Factor	Low level	High level
Material IV [dL/g]	0.74	0.84
Material additive (TiO <sub>2</sub> ) [%]	0 (virgin)	10
Moisture content [ppm]	1433	3174

The process parameters were fixed (Table 3) for each factor and the equivalent stress and equivalent strain was then determined and compared to demonstrate the effect of material/preform condition. Figure 2 shows the stress strain behaviour for each factor.

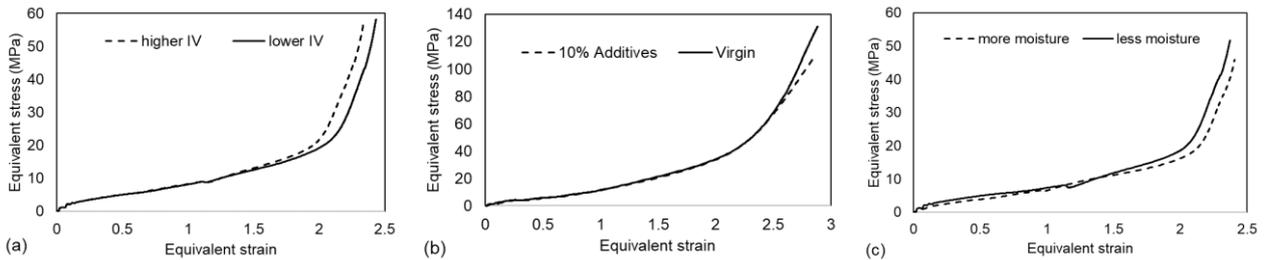


Fig. 2 Stress strain behaviour for preform condition factor (a) material additive, (b) IV value and (c) moisture content.

The difference in the material response due to the change in preform/material condition was quantified by comparing the mean deviation and found to be 11.7%, 4.3% and 8.5% for IV, additive and moisture content respectively. The lower material response from the low IV was a result of the reduced molecular chain length and entanglement. The lower material response due to additive content was due to the additive acting as a plasticiser and increasing chain mobility. Similarly with moisture content, the water molecules acted as a plasticiser between the polymer chains and increasing chain mobility.

## Conclusion

A novel method of analysing the preform and material collectively had been presented. Differences in the material grade and preform condition can be effectively determined and quantified. Using the subject preform for the analysis along with the actual blowing conditions, this quick testing method is more relevant to the SBM process when compared to other testing methods such as IV analysis, biaxial stretching and polarised light analysis. This becomes a valuable tool for the SBM industry as information previously unavailable can optimise and improve the bottle forming process; namely preform, new material assessment and process optimisation.

## References

- [1] blah
- [2] blah
- [3] blah