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Formability Characterization of Composite Sheet Materials by Erichsen Cupping Testing Method

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Abstract: Erichsen cupping testing can be used for grading, selecting and sorting of incoming composite materials for manufacturing of various sheet materials application. The objective of this experiment is to find out the Erichsen number (EN) of unidirectional laminated polymer composite sheet materials by Erichsen cupping testing machine (Model ET-20, least count of 0.01 mm) in forming operations (stretching). In the Erichsen test, the punch is pressed into the sheet until fracture occurs, at which point the test is stopped immediately and the depth of the bulge noted. This depth (mm) gives the Erichsen number. The Erichsen number obviously gives a measure of the ductility of the sheet in the plane of drawing under biaxial stress condition. It is observed from the present experiment that in general the Erichsen number is influenced by fiber and matrix properties, orientation of fiber, and thickness of the sheet material. In this experiment a total force of around 10 KN was applied on the sample sheet materials by a ball shaped indenter (20mm diameter) until the cracks begin to occur in the specimen.
Keywords: Forming operation (stretching);Composite sheet material; Erichsen number (EN); Molecular modeling.

Introduction and Experimental:

Sheet material formability is the ability of sheet material to undergo desired shape change without failure. The Erichsen cupping test is a ductility test, which is employed to evaluate the ability of sheets material and strips to undergo plastic deformation in stretch forming [ref.1 & ref.3]. Formability tests [ref.6] would allow better quantification of the formability of sheet metals, taking into account the synergistic interaction of sheet metals intrinsic properties and the processing conditions existing during processing operations. Checking of scatter in modified Erichsen cupping test results [ref.4 and ref.7]. Polymer matrix composites increasingly employed in industrial application because of their unique combination of mechanical, electrical and thermal properties, have high specific strength and modulus, excellent fracture toughness, fatigue properties , good corrosion resistance, thermal and electrical resistance properties(ref.9). It is, therefore, essential to have tests that simulate the processing conditions and deformation modes existing during the industrial forming, of sheet metal components [ref.2].Formability should be viewed more as system parameters, as it is a function of the sheet metal that is being formed, the process conditions, the forming press, and the component shape [ref.4].

A high strain hardening exponents related to the ability of sheet material to undergo large uniform strains during biaxial stretching operations [ref.3]. To find out unidirectional fiber reinforced thermoplastic polymer sheet formability properties for road side restraints system application as barrier and pole materials. Uses of thermoplastic polymer composite is likely to bring both economic (e.g. utilization of recycled plastic) and functional benefits. Road side restraint systems are widely used to control the flow of traffic and raise road safety (passenger and pedestrians).Road side restraint system based on polymer matrix composites will give reduction maintenance cost, weight reduction, corrosion resistance, impact resistance and protection against vehicles internal parts damage. In the process, the material was subjected to a short-term heating to 200°C, causing softening and partial melting of the inner LDPE sheet and penetration of the polymer into the glass reinforcement. As cooling method, quenching was applied in order to eliminate negative effects of crystallized. During slow cooling, structure changes from amorphous to crystalline structure and crystalline structure shows more brittle property. A uniform feed of Ball penetrator (0.1 mm/sec.) was provided. The machine was operated at 4.8 rpm by hand wheel as the pitch 5mm with ratio 4:1.Accelrys Materials Studio 6.1 is a suite of molecular dynamics modeling software that is used in advanced modeling of various materials (polymers, nanotubes, catalysts, metals, ceramics, composite etc. Molecular Dynamics modeling is a computer simulation of atoms and molecules interacting with each other.

Result and Discussion:

From experimental table we have found that for same fiber orientated polymer composite sheet Erichsen Index decreases with decrease in thickness i.e. bad stretching formability).For different fiber orientated polymer composite sheet materials Erichsen index no. varies with thickness as well as more angle fiber orientated. There is also variation of Erichsen Index with speed as Erichsen Index decreases with increase in speed. By analyzing the four FLD curves, it is reported that fiber addition to the composite brought up more stiffness to the composite. Besides the increase in stiffness, an increase in elongation was also noticed for the reinforced composite. They not only show the presence of low safe strains for the cross fiber composite but they also mention that most of the safe strains are located on the FLD left side. Molecular modeling by materials studio 6.1 is given in as below:

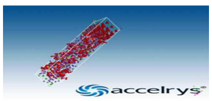
Simulation Cell details	**Geometry optimization Parameter with value**	**Dynamic run Parameters with value**	**Mechanical Parameters with value and properties**	**Interaction Energy details**
E-Glass fiber/Polyethylene  3D-TRICLINIC (10 Å x 10 Å x 54 Å) , 1183 atoms	Algorithm ,Quality convergence tolerance ,Energy convergence tolerance ,Force convergence tolerance, Displacement convergence tolerance Maximum no. of iterations, Value:Smart,Medium,0.001Kcal /mol,0.5 Kcal/mol,0.5Kcal/mol 0.015Å,5000	Ensemble ,Initial velocity Temperature ,Time step Total simulation time, No. of steps,Frame output every Thermostat ,Collision ratio Energy deviation, Repulsive cut-off, NVE, Random,298K,1 fs, 0.5 ps,500,500,5000 Kcal/mol	Number of strains ,Maximum strain Pre-optimize structure,Algorithm Maximum number of iterations Forcefield , Repulsive cut-off Longitudinal Young's modulus (E11), GPa ,Transverse Young's modulus (E22), GPa ,Poisson's ratio(v12) Shear modulus (G23), GPa Bulk modulus, (K23), GPa **4,0.003,Yes,Smart,5000,**	**-13791 Kcal/mol**
Cyanoacrylate/E Glass Fiber  3D-TRICLINIC (10 Å x 10 Å x 55 Å) , 1404 atoms	Algorithm ,Quality convergence tolerance ,Energy convergence tolerance ,Force convergence tolerance, Displacement convergence tolerance Maximum no. of iterations, Value:Smart,Medium,0.001Kcal /mol,0.5 Kcal/mol,0.5Kcal/mol 0.015Å,5000	Ensemble ,Initial velocity Temperature ,Time step Total simulation time, No. of steps,Frame output every Thermostat ,Collision ratio Energy deviation, Repulsive cut-off, NVE, Random,298K,1 fs, 0.5 ps,500,500,5000 Kcal/mol	Number of strains,Maximum strain Pre-optimize structure,Algorithm Maximum number of iterations Forcefield ,Repulsive cut-off Longitudinal Young's modulus (E11), GPa ,Transverse Young's modulus (E22), GPa ,Poisson's ratio(v12) Shear modulus (G23), GPa Bulk modulus, (K23), GPa **4,0.003,Yes,Smart,5000,**	**-5691 Kcal/mol**
Cyanoacrylate/PE  3D-TRICLINIC (10 Å x 10 Å x 55 Å) , 481 atoms	Algorithm ,Quality convergence tolerance ,Energy convergence tolerance ,Force convergence tolerance, Displacement convergence tolerance Maximum no. of iterations, Value:Smart,Medium,0.001Kcal /mol,0.5 Kcal/mol,0.5Kcal/mol 0.015Å,5000	Ensemble ,Initial velocity Temperature ,Time step Total simulation time, No. of steps,Frame output every Thermostat ,Collision ratio Energy deviation, Repulsive cut-off, NVE, Random,298K,1 fs, 0.5 ps,500,500,5000 Kcal/mol	Number of strains ,Maximum strain Pre-optimize structure ,Algorithm Maximum number of iterations Forcefield,Repulsive cut-off Longitudinal Young's modulus (E11), GPa ,Transverse Young's modulus (E22), GPa ,Poisson's ratio(v12) Shear modulus (G23), GPa Bulk modulus, (K23), GPa 4,0.003,Yes,Smart,5000,	-48.58 Kcal/mol

Table no. 1: Result of Erichsen cupping test

Serial No	Matrix	Fiber	Sample	Thickness of Sheet (mm)	Machine Reading (mm)	Zero Error (mm)	Total Reading (mm)	Erichsen Index (IE)	Force on Spindle
1	Low density polyethylene	E-glass	$[0/90]_s$	10.00	11.47	-0.02	11.45	11.45	10KN
2	Low density polyethylene	E-glass	$[0/90]_{2s}$	20.00	12.30	-0.02	12.28	12.28	
3	Low density polyethylene	E-glass	$[\pm 45]_s$	10.00	11.82	-0.02	11.80	11.80	
4	Low density polyethylene	E-glass	$[\pm 45]_{2s}$	20.00	12.64	-0.02	12.62	12.62	

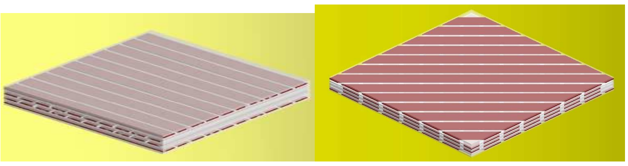
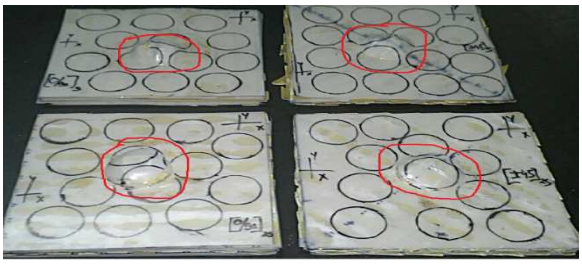


Fig no. 1: Sample PMC $[0/90]_s$ & PMC $[\pm 45]_s$.



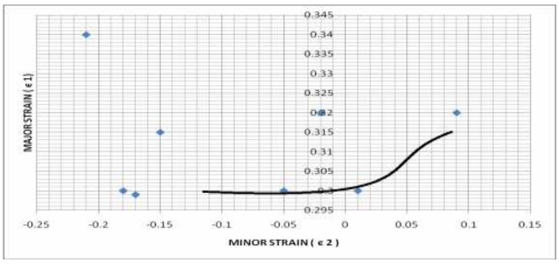


Figure no.2: samples after cupping test.

Figure no.3: FLD for $[\pm 45]_{2s}$ sample.

Conclusions:

From the experiment they concluded that more the Erichsen Index of a material more the stretching formability property of the material and is more suitable for general use than ones with lower index. The stretching formability property of the material varies with thickness, speed of spindle and temperature of the four sheet materials. The addition of fibers in a random distribution makes the PMC sheets more susceptible to stretching operations. The safe strains are located on the FLD left side, which makes impossible the existence of a biaxial tensile stress field. The obtained results are very encouraging and open a new market for the recycling process.

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