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The Influence of Creep on the Mechanical Properties of Calcium Carbonate Nanofiller Reinforced Polypropylene

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ABSTRACT

The study focused on experimental and classical data to establish some mechanical properties for optimum design of new polypropylene components to serve under creep environment. The creep studies recorded stress limits that never exceeded 24.19MPa and maximum creep modulus that never exceeded 1.49GPa as against the predictions of classical equations that gave 2.0GPa for PPC0 and 2.46GPa for PPC2 at ambient conditions. The shear modulus and shear strength of the PPC0 and the PPC2 are predicted as 0.75GPa and 120MPa respectively and 0.92GPa and 150MPa respectively while the yield strengths found to be about 13.19MPa and 13.20MPa respectively for PPC0 and PPC2 at elastic strains 0.008 and 0.009 respectively. Further found are that as the material deforms the stiffness or modulus decrease, at low strains there is an elastic region, as temperature and applied stress increase the material becomes more flexible characterized with reduction in moduli. Plastic deformation at strains above 0.01 resulted to strain- hardening or strain-strengthening that manifested as the increasing area ratios and associated creep cold work. Also established by this study is a computational model for evaluating the elastic modulus of polypropylene matrix based material as expressed in equation (6). Both the Halphin-Tsai and the Birintrup equations for elastic modulus of unidirectional fibre composites were confirmed to be appropriate for prediction of elastic modulus of nanofiller composites with polymer matrix.

Keywords: *Influence of creep, Mechanical properties, Calcium carbonate nanofiller, Reinforced Polypropylene.*

1. INTRODUCTION

Polymeric materials exhibit properties which come somewhere between elastic and viscous properties and are controlled by elastic and viscous constants called modulus and viscosity respectively making the mechanical properties of plastics to be viscoelastic [1]. This means that they vary with time under load, the rate of loading and the temperature and the creep limits of plastic composites need to be established because of involvement of plastics in most recent designs such as in multi-layer moldings, design of snap fits, design of ribbed sections and in design of light weight structures in everyday use.

Young's modulus is low for plastics and never constant compared with metals; resistance to deflection (stiffness) is often a concern regarding the use of plastics and the stiffness of a structure is dependent on the elastic modulus of the material and the part geometry.

Though many scholars such as [2-8] have worked extensively on the reinforcement of polypropylene with calcium carbonate nanofiller, studies are yet to advance on the limiting creep properties of polypropylene composites with calcium carbonate nanofiller. This study in order to address this pertinent issue used experimental and classical results to study the creep limiting properties of polypropylene and its calcium carbonate nanofiller composite.

Most mechanical properties are structure –sensitive and are therefore affected by changes in either the lattice structure or the microstructure. However modulus of elasticity is one property that is structure insensitive. The modulus of elasticity of material is the same regardless of grain size, amount of cold work, or microstructure while the ductility and toughness that are structure sensitive vary with the amount of cold work and/or grain size. When a crystalline material is plastically deformed, there is an avalanche of dislocations called slip that terminates at the grain boundaries, leading to mass movement of a body of atoms along a crystallographic plane [9].

2. METHODOLOGY

The methods of this study used the experimental tensile and tensile creep test results conducted on calcium carbonate nanofiller reinforced polypropylene composite by [10] with classical data and relations to evaluate the limiting properties of polypropylene as a new material.

2.1. Use of Classical Relations of Composite Elastic Modulus

The mass of a composite is the sum of the masses of the matrix (polymer) and the re-enforcing phase (filler). The properties of a composite material are then function of the starting materials [11] so that the following relations are found in literature for estimating the elastic modulus of particulate fillers [8] . The modulus of elasticity of the particle filled composite may be predicted using the following equations:

$$E_c = E_P\varphi_p + E_f\varphi_f \qquad (1)$$

$$E_c = \frac{E_P E_f}{E_p\varphi_f + E_f\varphi_p} \qquad (2)$$

$$E = E_m[1 + 2.5\varphi + 14.1\varphi^2] \qquad (3)$$

where E = Modulus of elasticity, φ = volume fractions, Subscripts c, f and p represent the composites, filler and polymer.

2.1.1 Estimation of elastic modulus of the composite

The elastic modulus of the composite estimated with equations (1, 2 and 3) in [10] is as presented in Table 1.

Table 1: Computed Composite Modulus with Existing Relations

φ_p	φ_f	Eq.(1), E(GPa)	Eq.(2), E(GPa)	Eq.(3), E(GPa)
0.95	0.05	3.162	2.05500444	2.21191
0.9	0.01	2.024	2.17595518	2.00928
0.85	0.15	5.566	2.27560954	2.75718
0.8	0.2	6.768	2.40468101	3.05054
0.75	0.25	7.97	2.54927464	3.35773
0.7	0.3	9.172	2.7123696	3.67872
0.65	0.35	10.374	2.89775958	4.01354
0.6	0.4	11.576	3.11035156	4.36218
0.55	0.45	12.778	3.35660651	4.72463
0.5	0.5	13.98	3.64520744	5.1009
0.4	0.6	16.384	4.40221147	5.8949

This study further employed the Halphin-Tsai and Brintrup equations for composite modulus expressed in equation (4 and 5) respectively [12] to come up with simpler and if possible better approximation for composite elastic modulus.

$$E = E_m\left(\frac{1+2\beta\varphi}{1-\beta\varphi}\right) \qquad (4)$$

Where

$$\beta = \frac{(E_f/E_m)-1}{(E_f/E_m)+2} \qquad (4a)$$

$$E = \frac{E^m E_f}{E_f(1-)+\varphi E^m} \quad (5)$$

$$E^m = E_m/(1 - \nu^2{}_m) \quad (5a)$$

Where

ν_m = Poisson ratio and for PP = 0.34.

The estimations of composite elastic modulus with equations (4 and 5) are presented in Table 2

Table 2: Composites elastic modulus with equations (4 and 5)

Specimen code	V_m	$V_f = \varphi$	E_H	E_B	$(E_H + E_B)/2 = E$
PPCO	1	0	1.96	2.22	2.09
PPC1	0.95	0.05	2.21	2.33	2.27
PPC2	0.9	0.1	2.47	2.44	2.46
PPC3	0.85	0.15	2.77	2.57	2.67
PPC4	0.8	0.2	3.09	2.72	2.91
PPC5	0.75	0.25	3.44	2.88	3.16

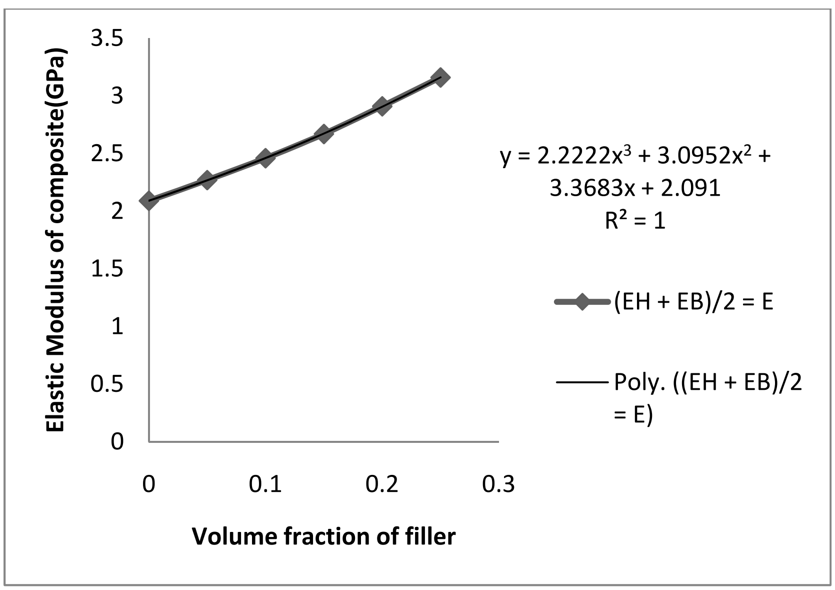


Figure 1: Elastic Modulus – Volume fraction of Filler

Through Figure 1 generated from predictions of Table 2 a cubic polynomial equation relating elastic modulus and volume fraction was established in this study as

$$E = 2.222\varphi^3 + 3.095\varphi^2 + 3.368\varphi + 2.091 \quad (6)$$

2.2. Creep Testing and Computations

TecQuipment creep equipment, model SM106 MKII was used to test PP and PPCaCO$_3$ nanofiller composite of various volume fractions of CaCo$_3$ nano filler at temperatures 25^{O}C, 50^{O}C and 70 ^{O}C respectively at various stresses to establish creep properties of the PPCaCO$_3$ nanofiller composite [10] and the results presented in the following tables with the instantaneous cross sectional area of sample A_f, creep modulus E (t) and creep compliance C (t) evaluated according to the relations of [9,12] expressed as follows

$$\mathcal{E} = \ln\frac{A_O}{A_f} \qquad (7)$$

Where Ɛ is the true strain or natural strain expressed as

$$\mathcal{E} = \ln(n+1) \qquad (7a)$$

Where n is the nominal strain or the engineering strain evaluated during the tensile test by measuring the percentage elongation of specimen

$$E(t) = \frac{s}{\mathcal{E}(t)} \qquad (8)$$

The creep modulus will vary with time, i.e decrease as time increases; sometimes creep compliance is used instead of creep modulus and is expressed as

$$C(t) = \frac{1}{E(t)} = \frac{\mathcal{E}(t)}{s} \qquad (9)$$

where s is the constant creep stress and Ɛ(t) is the natural strain at time t. In this work n(t) = Ɛ(t) and σ is the measured stress at experimental time t. The experimental creep results are presented in Tables 3-12.

Table 3: Experimental Creep Results obtained for PPC-0 at 13.08MPa, 25^{0}C Ambient Condition

t(hrs)	Ɛ(t)	A_f	Arr	σ(MPa)	Ei(GPa)	E(t)(MPa)	C(t) (MPa^{-1})
0.000	0.008	2381	1.0079798	13.19	1.6490	1.688	0.592
0.277	0.010	2376.1	1.0100585	13.21	1.3210	1.350	0.741
0.555	0.012	2371.4	1.0120604	13.24	1.1033	1.125	0.899
0.833	0.015	2364.3	1.0150996	13.28	0.8853	0.900	1.111
1.111	0.016	2361.9	1.0161311	13.29	0.8306	0.844	1.185

1.388	0.017	2359.5	1.0171647	13.3	0.7824	0.794	1.259
1.667	0.018	2357.2	1.0181571	13.32	0.7400	0.750	1.333
1.944	0.019	2354.8	1.0191948	13.33	0.7016	0.711	1.406
2.222	0.021	2350.1	1.0212331	13.36	0.6362	0.643	1.555
2.500	0.022	2347.8	1.0222336	13.37	0.6077	0.614	1.629
2.778	0.024	2343.1	1.0242841	13.4	0.5583	0.563	1.776
3.056	0.028	2333.7	1.0284098	13.45	0.4804	0.482	2.075
3.333	0.030	2329.1	1.0304409	13.48	0.4493	0.45	2.222
3.611	0.031	2326.7	1.0315038	13.49	0.4352	0.435	2.299
3.889	0.031	2326.7	1.0315038	13.49	0.4352	0.435	2.299
4.167	0.032	2324.4	1.0325245	13.51	0.4222	0.422	2.37
4.444	0.032	2324.4	1.0325245	13.51	0.4222	0.422	2.37

Table 4: Experimental Creep Results obtained for PPC-2 at 13.08MPa, 25^0C Ambient Condition

t(hrs)	ε(t)	A_f	Arr	σ(MPa)	Ei(GPa)	E(t)(MPa)	C(t) (MPa^{-1})
0	0.009	2378.5	1.0090	13.2	1.4667	1.489	0.672
0.277	0.012	2371.4	1.0120	13.24	1.1033	1.117	0.895
0.555	0.013	2369	1.0130	13.25	1.0192	1.031	0.97
0.833	0.015	2364.3	1.0151	13.28	0.8853	0.893	1.12
1.111	0.017	2359.5	1.0171	13.3	0.7824	0.788	1.269
1.388	0.018	2357.2	1.0181	13.32	0.74	0.744	1.3
1.667	0.019	2354.8	1.0191	13.33	0.7016	0.705	1.425
1.944	0.02	2352.5	1.0201	13.34	0.667	0.67	1.499
2.222	0.021	2350.1	1.0212	13.36	0.6362	0.638	1.572
2.5	0.023	2345.4	1.0232	13.38	0.5817	0.583	1.719
2.778	0.024	2343.1	1.0242	13.4	0.5583	0.558	1.791
3.056	0.025	2340.7	1.0253	13.41	0.5364	0.536	1.868
3.333	0.026	2338.4	1.0263	13.42	0.5162	0.515	1.937
3.611	0.028	2333.7	1.0283	13.45	0.4804	0.479	2.082
3.889	0.029	2331.4	1.0294	13.46	0.4641	0.462	2.155
4.167	0.03	2329.1	1.0304	13.48	0.4493	0.447	2.226
4.444	0.03	2329.1	1.0304	13.48	0.4493	0.447	2.226

Table 5: Experimental Creep Results obtained for PPC-0 at 19.60MPa, 25^{0}C Ambient Condition.

t(hrs)	Ɛ(t)	A_f	Arr	σ(MPa)	Ei(GPa)	E(t)(MPa)	C(t) (MPa^{-1})
0	0.015	2364.3	1.01511249	19.9	1.3264	1.353	0.739
0.28	0.03	2329.1	1.03045422	20.2	0.6732	0.677	1.477
0.56	0.033	2322.1	1.03355167	20.26	0.6139	0.615	1.626
0.83	0.035	2317.5	1.03562105	20.3	0.58	0.58	1.724
1.11	0.037	2312.8	1.03769424	20.34	0.5497	0.549	1.821
1.39	0.04	2305.9	1.04081287	20.4	0.51	0.508	1.969
1.67	0.042	2305.9	1.04081287	20.44	0.4867	0.483	2.07
1.94	0.045	2301.3	1.04289333	20.5	0.4556	0.451	2.217
2.22	0.048	2294.4	1.04602966	20.56	0.4283	0.423	2.364
2.5	0.05	2283	1.05127138	20.6	0.4121	0.406	2.463
2.78	0.053	2276.1	1.05443059	20.67	0.3899	0.383	2.611
3.06	0.056	2269.3	1.05759951	20.73	0.3702	0.363	2.755
3.33	0.058	2264.8	1.05971494	20.77	0.3581	0.35	2.857
3.61	0.06	2260.2	1.06183414	20.81	0.3469	0.338	2.959

Table 6: Experimental Creep Results obtained for PPC-2 at 19.60MPa, 25^{0}C Ambient Condition.

t(hrs)	Ɛ(t)	A_f	Arr	σ(MPa)	Ei(GPa)	E(t)(MPa)	C(t) (MPa^{-1})
0	0.015	2364.3	1.01511	19.9	1.3264	1.353	0.739
0.28	0.029	2331.4	1.02942	20.18	0.6958	0.7	1.429
0.56	0.032	2324.4	1.03251	20.24	0.6324	0.634	1.577
0.83	0.033	2322.1	1.03355	20.26	0.6139	0.615	1.626
1.11	0.034	2319.8	1.0345	20.28	0.5964	0.597	1.675
1.39	0.035	2317.5	1.03562	20.3	0.58	0.58	1.724
1.67	0.036	2312.8	1.03769	20.34	0.565	0.563	1.776
1.94	0.038	2310.5	1.03873	20.36	0.5358	0.534	1.873
2.22	0.039	2308.2	1.03977	20.38	0.5226	0.521	1.919
2.5	0.04	2305.9	1.04081	20.4	0.51	0.508	1.969
2.78	0.042	2301.3	1.04289	20.44	0.4867	0.483	2.07
3.06	0.044	2296.7	1.04498	20.48	0.4655	0.461	2.169

3.33	0.046	2292.1	1.04707	20.52	0.4461	0.441	2.268
3.61	0.05	2283	1.05127	20.6	0.4121	0.406	2.463

Table 7: Experimental Creep Results obtained for PPC-0 at 22.87MPa, 25^{0}C Ambient Condition

t(hrs)	Ɛ(t)	A_f	Arr	σ(MPa)	Ei(GPa)	E(t)(MPa)	C(t) (MPa^{-1})
0	0.019	2354.8	1.01918185	23.31	1.2268	1.263	0.792
0.056	0.02	2352.5	1.02019996	23.33	1.1167	1.2	0.833
0.083	0.021	2350.1	1.0212201	23.36	1.1122	1.143	0.875
0.139	0.03	2329.1	1.03045422	23.57	0.7856	0.8	1.25
0.222	0.033	2322.1	1.03355167	23.64	0.7163	0.727	1.376
0.278	0.04	2305.9	1.04081287	23.8	0.5951	0.6	1.667
0.417	0.046	2296.7	1.04498213	23.9	0.5195	0.522	1.916
0.556	0.05	2283	1.05127138	24.04	0.4809	0.48	2.083
0.694	0.052	2278.4	1.05337541	24.09	0.4633	0.462	2.165
0.833	0.056	2269.3	1.05759951	24.19	0.4319	0.429	2.331

Table 8: Experimental Creep Results obtained for PPC-2 at 22.87MPa, 25^{0}C Ambient Condition

t(hrs)	Ɛ(t)	A_f	Arr	σ(MPa)	Ei(GPa)	E(t)(MPa)	C(t) (MPa^{-1})
0	0.019	2354.8	1.01918185	23.31	1.2268	1.263	0.792
0.056	0.02	2352.5	1.02019996	23.33	1.1167	1.2	0.833
0.083	0.021	2350.1	1.0212201	23.36	1.1122	1.091	0.917
0.139	0.03	2329.1	1.03045422	23.57	0.7856	0.615	1.626
0.222	0.033	2322.1	1.03355167	23.64	0.7163	0.571	1.751
0.278	0.04	2305.9	1.04081287	23.8	0.5951	0.522	1.916
0.417	0.046	2296.7	1.04498213	23.9	0.5195	0.5	2
0.556	0.05	2283	1.05127138	24.04	0.4809	0.48	2.083
0.694	0.052	2278.4	1.05337541	24.09	0.4633	0.462	2.165
0.833	0.056	2269.3	1.05759951	24.19	0.4319	0.429	2.331

Table 9: Experimental Creep Results obtained for PPC-0 at 50°C, and Stress of 13.08MPa

t(hrs)	Ɛ(t)	A_f	Arr	σ(MPa)	Ei(GPa)	E(t)(MPa)	C(t) (MPa^{-1})
0.083	0.02	2352.5	1.0202043	13.34	0.667	0.695	1.439
0.167	0.022	2347.9	1.02219875	13.37	0.608	0.632	1.582
0.25	0.03	2329	1.03049846	13.48	0.449	0.463	2.16
0.333	0.034	2319.8	1.03458087	13.53	0.398	0.409	2.444
0.417	0.04	2305.9	1.04080836	13.61	0.34	0.348	2.874
0.5	0.046	2292.1	1.04707017	13.7	0.298	0.302	3.311
0.583	0.05	2283	1.05127138	13.75	0.275	0.278	3.597
0.667	0.058	2264.8	1.05971026	13.86	0.239	0.24	4.167
0.75	0.058	2264.8	1.05971026	13.86	0.239	0.24	4.167
0.833	0.058	2264.8	1.05971026	13.86	0.239	0.24	4.167

Table 10: Experimental Creep Results obtained for PPC-2 at 50°C, and Stress of 13.08MPa

t(hrs)	Ɛ(t)	A_f	Arr	σ(MPa)	Ei(GPa)	E(t)(MPa)	C(t) (MPa^{-1})
0.083	0.018	2357.2	1.01816145	13.32	0.74	0.767	1.304
0.167	0.022	2347.9	1.02219875	13.37	0.608	0.627	1.595
0.25	0.026	2338.4	1.0263428	13.42	0.516	0.531	1.883
0.333	0.03	2329	1.03049846	13.48	0.449	0.46	2.174
0.417	0.033	2322.1	1.03355167	13.52	0.41	0.418	2.392
0.5	0.04	2305.9	1.04080836	13.61	0.34	0.345	2.899
0.583	0.046	2292.1	1.04707017	13.7	0.298	0.3	3.333
0.667	0.05	2283	1.05127138	13.75	0.275	0.276	3.623
0.75	0.054	2273.8	1.05548324	13.81	0.256	0.256	3.906
0.833	0.058	2264.8	1.05971494	13.86	0.239	0.238	4.202

Table 11: Experimental Creep Results obtained for PPC-0 at 70°C, and Stress of 13.08MPa

t(hrs)	Ɛ(t)	A_f	Arr	σ(MPa)	Ei(GPa)	E(t)(MPa)	C(t) (MPa^{-1})
0.083	0.019	2354.8	1.01919916	13.33	0.702	0.737	1.357
0.167	0.025	2340.7	1.02532116	13.41	0.536	0.56	1.786

0.25	0.038	2310.6	1.03870024	13.59	0.358	0.368	2.717
0.333	0.05	2283	1.05127138	13.75	0.275	0.28	3.571
0.417	0.056	2269.3	1.05759951	13.83	0.247	0.25	4
0.5	0.063	2253.5	1.06502889	13.93	0.221	0.222	4.505
0.583	0.069	2240	1.07143814	14.01	0.203	0.203	4.926
0.667	0.075	2226.6	1.07788627	14.01	0.188	0.187	5.348

Table 12: Experimental Creep Results obtained for PPC-2 at 70°C, and Stress of 13.08MPa

t(hrs)	Ɛ(t)	A_f	Arr	σ(MPa)	Ei(GPa)	E(t)(MPa)	C(t) (MPa^{-1})
0.083	0.005	2388	1.0050125	13.15	2.63	2.68	0.373
0.167	0.01	2376.1	1.01005	13.21	1.321	1.34	0.746
0.25	0.015	2364.5	1.01501374	13.28	0.885	0.893	1.12
0.333	0.02	2352.5	1.02019996	13.34	0.667	0.67	1.493
0.417	0.023	2345.4	1.02327089	13.38	0.582	0.583	1.715
0.5	0.025	2340.7	1.02532116	13.41	0.536	0.536	1.866
0.583	0.03	2329.1	1.03045422	13.48	0.449	0.447	2.237
0.667	0.035	2317.5	1.03562105	13.55	0.387	0.383	2.611

2.2.1 Estimation of amount of cold work

The amount of cold work is defined as the percentage of reduction of cross-sectional area that is given the material by a plastic deformation process and is expressed mathematically as

$$W = \frac{A_0 - A_f}{A_0}(100) = \left(1 - \frac{A_f}{A_0}\right)(100) = \left(1 - \frac{1}{Arr}\right)(100) \quad (10)$$

The area ratios of all the operations are presented in Tables 3-12 as summarized in Table 13. Equation (10) is then employed with excel tools to compute the amount of cold work as presented in table 14a and b, where the symbols Arr3-Arr12 represented the area ratios associated with Tables 3-12 and W3-W12 represented the cold work associated.

Table 13: Depiction of Area Ratios of all Creep Conditions

Arr3	Arr4	Arr5	Arr6	Arr7	Arr8	Arr9	Arr10	Arr11	Arr12
1.008	1.009	1.0151	1.0151	1.0192	1.0192	1.0202	1.0182	1.0192	1.005

1.0101	1.012	1.0305	1.0294	1.0202	1.0202	1.0222	1.0222	1.0253	1.0101
1.0121	1.013	1.0336	1.0325	1.0212	1.0212	1.0305	1.0263	1.0387	1.015
1.0151	1.0151	1.0356	1.0336	1.0305	1.0305	1.0346	1.0305	1.0513	1.0202
1.0161	1.0171	1.0377	1.0345	1.0336	1.0336	1.0408	1.0336	1.0576	1.0233
1.0172	1.0181	1.0408	1.0356	1.0408	1.0408	1.0471	1.0408	1.065	1.0253
1.0182	1.0191	1.0408	1.0377	1.045	1.045	1.0513	1.0471	1.0714	1.0305
1.0192	1.0201	1.0429	1.0387	1.0513	1.0513	1.0597	1.0513	1.0779	1.0356
1.0212	1.0212	1.046	1.0398	1.0534	1.0534	1.0597	1.0555		
1.0222	1.0232	1.0513	1.0408	1.0576	1.0576	1.0597	1.0597		
1.0243	1.0242	1.0544	1.0429						
1.0284	1.0253	1.0576	1.045						
1.0304	1.0263	1.0597	1.0471						
1.0315	1.0283	1.0618	1.0513						
1.0315	1.0294								
1.0325	1.0304								
1.0325	1.0304								

Table 14a: Cold Work Results of Operations

Arr3	Arr4	Arr5	Arr6	Arr7	W3	W4	W5	W6	W7
1.008	1.009	1.0151	1.0151	1.0192	0.791663	0.891972	1.48875	1.488509	1.882083
1.0101	1.012	1.0305	1.0294	1.0202	0.995833	1.185771	2.955417	2.85792	1.98
1.0121	1.013	1.0336	1.0325	1.0212	1.191668	1.283317	3.24625	3.148638	2.077916
1.0151	1.0151	1.0356	1.0336	1.0305	1.487499	1.487538	3.439583	3.246094	2.955417
1.0161	1.0171	1.0377	1.0345	1.0336	1.587502	1.681251	3.6325	3.334944	3.24625
1.0172	1.0181	1.0408	1.0356	1.0408	1.687504	1.777821	3.92125	3.439486	3.92125
1.0182	1.0191	1.0408	1.0377	1.045	1.78333	1.874203	3.92125	3.632106	4.304584
1.0192	1.0201	1.0429	1.0387	1.0513	1.88333	1.970395	4.112916	3.728592	4.877083
1.0212	1.0212	1.046	1.0398	1.0534	2.079163	2.075989	4.400416	3.824884	5.067083
1.0222	1.0232	1.0513	1.0408	1.0576	2.175002	2.267396	4.877083	3.920985	5.44625
1.0243	1.0242	1.0544	1.0429		2.370836	2.36282	5.162084	4.11261	
1.0284	1.0253	1.0576	1.045		2.762498	2.46757	5.44625	4.304389	
1.0304	1.0263	1.0597	1.0471		2.954163	2.562604	5.635	4.495401	
1.0315	1.0283	1.0618	1.0513		3.054162	2.752115	5.823333	4.876958	
1.0315	1.0294				3.054162	2.856033			
1.0325	1.0304				3.149998	2.950311			
1.0325	1.0304				3.149998	2.950311			

Table 14b: Cold Work Results of Operations

Arr8	Arr9	Arr10	Arr11	ARR12	W8	W9	W10	W11	W12
1.0192	1.0202	1.0182	1.0192	1.005	1.882083	1.980417	1.78375	1.88375	0.49875
1.0202	1.0222	1.0222	1.0253	1.0101	1.98	2.171667	2.171667	2.469583	0.995
1.0212	1.0305	1.0263	1.0387	1.015	2.077916	2.959583	2.566667	3.725833	1.479166
1.0305	1.0346	1.0305	1.0513	1.0202	2.955417	3.3425	2.959583	4.877083	1.98
1.0336	1.0408	1.0336	1.0576	1.0233	3.24625	3.920833	3.24625	5.44625	2.274167
1.0408	1.0471	1.0408	1.065	1.0253	3.92125	4.495417	3.920833	6.105833	2.469583
1.045	1.0513	1.0471	1.0714	1.0305	4.304584	4.877083	4.495417	6.6675	2.955417
1.0513	1.0597	1.0513	1.0779	1.0356	4.877083	5.634584	4.877083	7.225834	3.439583
1.0534	1.0597	1.0555			5.067083	5.634584	5.256667		
1.0576	1.0597	1.0597			5.44625	5.634584	5.635		

2.2.2 Limit stress-cold work for PPC0 and PPC2

The influence of cold work on the strength property is shown on Table 15a and b.

Table 15a: Cold Work Results of Operations

σ3	σ4	σ 5	σ 6	σ 7	W3	W4	W5	W6	W7
13.19	13.2	19.9	19.9	23.31	0.791663	0.891972	1.48875	1.488509	1.882083
13.21	13.24	20.2	20.18	23.33	0.995833	1.185771	2.955417	2.85792	1.98
13.24	13.25	20.26	20.24	23.36	1.191668	1.283317	3.24625	3.148638	2.077916
13.28	13.28	20.3	20.26	23.57	1.487499	1.487538	3.439583	3.246094	2.955417
13.29	13.3	20.34	20.28	23.64	1.587502	1.681251	3.6325	3.334944	3.24625
13.3	13.32	20.4	20.3	23.8	1.687504	1.777821	3.92125	3.439486	3.92125
13.32	13.33	20.44	20.34	23.9	1.78333	1.874203	3.92125	3.632106	4.304584
13.33	13.34	20.5	20.36	24.04	1.88333	1.970395	4.112916	3.728592	4.877083
13.36	13.36	20.56	20.38	24.09	2.079163	2.075989	4.400416	3.824884	5.067083
13.37	13.38	20.6	20.4	24.19	2.175002	2.267396	4.877083	3.920985	5.44625
13.4	13.4	20.67	20.44		2.370836	2.36282	5.162084	4.11261	
13.45	13.41	20.73	20.48		2.762498	2.46757	5.44625	4.304389	
13.48	13.42	20.77	20.52		2.954163	2.562604	5.635	4.495401	
13.49	13.45	20.81	20.6		3.054162	2.752115	5.823333	4.876958	
13.49	13.46				3.054162	2.856033			
13.51	13.48				3.149998	2.950311			
13.51	13.48				3.149998	2.950311			

Table 15b: Cold Work Results of Operations

σ 8	σ 9	σ 10	σ 11	σ 12	W8	W9	W10	W11	W12
23.31	13.34	13.32	13.33	13.15	1.882083	1.980417	1.78375	1.88375	0.49875
23.33	13.37	13.37	13.41	13.21	1.98	2.171667	2.171667	2.469583	0.995
23.36	13.48	13.42	13.59	13.28	2.077916	2.959583	2.566667	3.725833	1.479166
23.57	13.53	13.48	13.75	13.34	2.955417	3.3425	2.959583	4.877083	1.98
23.64	13.61	13.52	13.83	13.38	3.24625	3.920833	3.24625	5.44625	2.274167
23.8	13.7	13.61	13.93	13.41	3.92125	4.495417	3.920833	6.105833	2.469583
23.9	13.75	13.7	14.01	13.48	4.304584	4.877083	4.495417	6.6675	2.955417
24.04	13.86	13.75	14.01	13.55	4.877083	5.634584	4.877083	7.225834	3.439583
24.09	13.86	13.81			5.067083	5.634584	5.256667		
24.19	13.86	13.86			5.44625	5.634584	5.635		

3. ESTIMATION OF SLIP IN POLYPROPYLENE MATERIALS

Slip will occur in polypropylene component when the yield strength is exceeded. The yield strength of polypropylene is in the range 12-43MPa [13]. Tables 3-12 showing creep stresses indicate the occurrence of lip due to low yield strength associated with creep. The shear strength of material is estimated with the classical relation

$$\tau = \frac{G}{2\pi} \tag{11}$$

where G is the shear modulus estimated with the relation

$$G = \frac{E}{2(1+\upsilon)} \tag{12}$$

So that by using the values E= 2GPa and ν = 0.34 the shear modulus and shear strength is evaluated for PPCO as 750MPa and 120MPa respectively and for PPC2 are 920MPa and 150MPa respectively.

4. DISCUSSION OF RESULTS

Table 1 and 2 show that the new PP (PPC2) has elastic modulus of 2-2.46GPa at optimum volume fraction of 0.10(10%) while table 2 distinctively show that neat PP(PPC0) has elastic modulus of about 2GPa at optimum volume fraction of 0.10.

Table 3 and 4 at 13.08MPa applied static stress and ambient condition 25^{O}C show the presence of primary creep stage, creep limit 13.51MPa, elastic modulus 1.35GPa at 0.01 natural strain, modulus at fracture 0.422GPa and fracture strain of 0.032 for neat PP (PPC0) and for PPC2 show the presence of primary creep stage, creep limit 13.48MPa, elastic modulus 1.49GPa at 0.01 natural strain, modulus at fracture 0.447GPa and fracture strain of 0.03.

Table 5 and 6 at 19.60MPa applied static stress and ambient condition 25^{O}C show the presence of primary creep stage with elastic strain 0.015 and modulus 1.353GPa, creep limit 20.81MPa, modulus at fracture 0.3338GPa and fracture strain of 0.06 for neat PP (PPC0) and for PPC2 show the presence of primary creep stage with elastic strain 0.015 and modulus 1.353GPa, creep limit 20.06MPa, modulus at fracture 0.406GPa and fracture strain of 0.05.

Table 7 and 8 at 22.88MPa applied static stress and ambient condition 25^{O}C show the presence of primary creep stage with elastic strain 0.015 and modulus 1.263GPa, creep limit 24.19MPa, modulus at fracture 0.429GPa and fracture strain of 0.056 for neat PP (PPC0) and for PPC2 show the presence of primary creep stage with elastic strain 0.019 and modulus 1.263GPa, creep limit 24.19MPa, modulus at fracture 0.429GPa and fracture strain of 0.056 also.

Table 9 and 10 at 13.08MPa applied static stress and ambient condition 50^{O}C show the absence of primary creep stage and presence of creep limit 13.86MPa, modulus at fracture 0.24GPa and fracture strain of 0.06 for neat PP (PPC0) and for PPC2 show the absence of primary creep stage and presence of creep limit 13.86MPa, modulus at fracture 0.24GPa and fracture strain of 0.06 also.

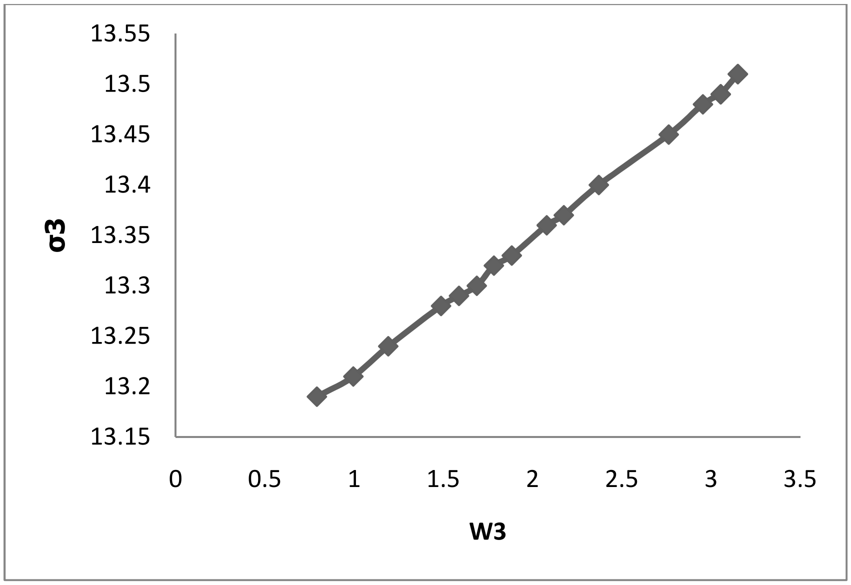
Table 11 and 12 at 13.08MPa applied static stress and ambient condition 70^{O}C show the absence of primary creep stage and presence of creep limit 14.01MPa, modulus at fracture 0.187GPa and fracture strain of 0.08 for neat PP (PPC0) and for PPC2 show the absence of primary creep stage and presence of creep limit 13.55MPa, modulus at fracture 0.383GPa and fracture strain of 0.035 The tensile strength of polypropylene is in the range 19.7-80MPa [12] by classical report and by experimental results of our previous report the tensile strength is 123MPa [10]. For the new material PPC2 our previous report gave the value of tensile strength as 45MPa [10]. From tables 3-12 the values of the recorded stress limits never exceeded 24.19MPa which is below the tensile limit obtained from classical reports showing the reducing influence of creep on the strength properties of PP. Further still on tables 3-12, notice that the maximum estimated elastic creep modulus at 1% natural strain approximately never exceeded 1.49GPa as against the predictions of classical equations that gave 2.0GPa for PPCO and 2.46GPa for PPC2. Creep therefore reduces the strength and stiffness properties of polypropylene and its nanofiller composites.
Tables 3-12 clearly show that as the material deforms the stiffness or modulus decrease, at low strains there is an elastic region, as temperature and applied stress increase the material becomes more flexible characterized with reduction in moduli.

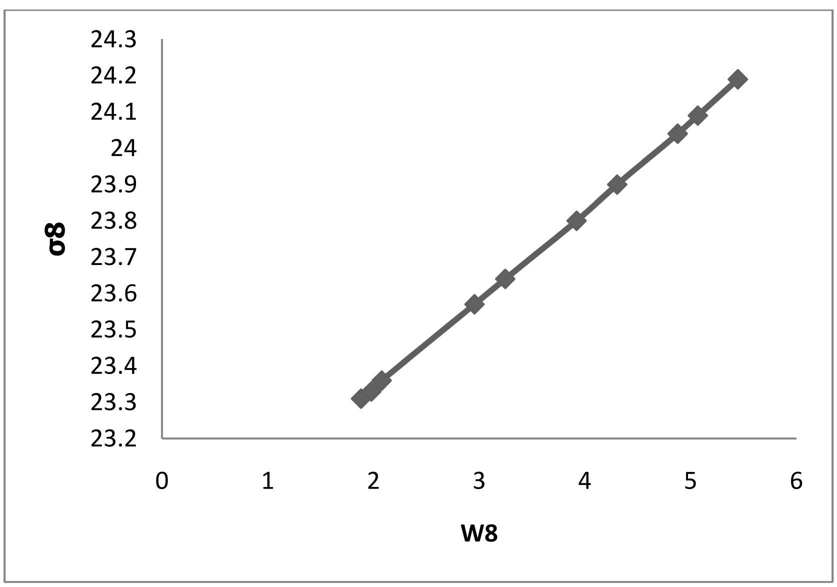
Plastic deformation at strains above 0.01 resulted to strain- hardening or stain-strengthening that manifested as the increasing area ratios and associated creep cold work as found in tables 3-12.

The stress-strain plots of tables 3-12 are linear graphs giving the strain-strengthening equation of plastic deformation when plotted on logarithmic graph [9] as

$$\sigma = c\mathcal{E}^{m} \qquad (11)$$

m is called the strain-strengthening exponent showing that strength increases with plastic strain operation increases. Figures 2 and 3 also show that the creep limit increases with increasing amount of cold work.





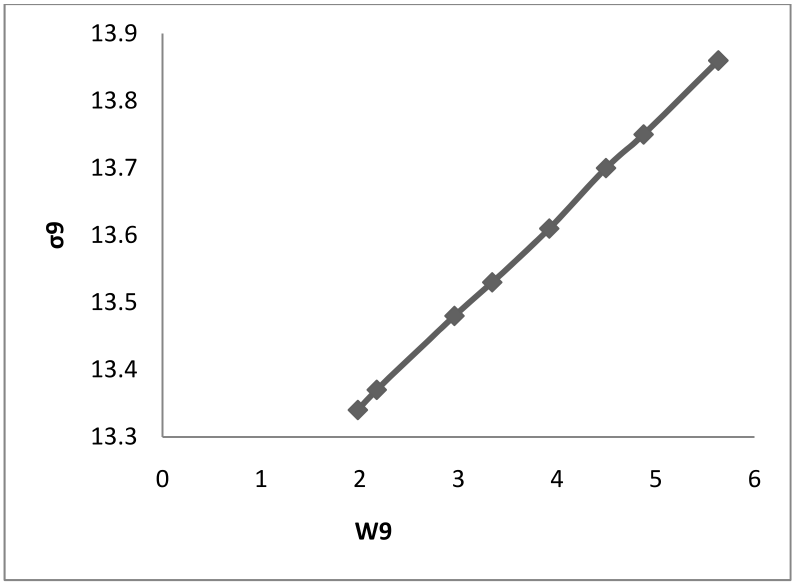


Figure 2a, b, and c: Depiction showing stress-cold work relationship in creep analysis

Table 3 and 4 established the shear strength of PPCO and PPC2 13.19MPa and 13.20MPa respectively at elastic strains of 0.008 and 0.009 while their shear moduli were estimated with equations (11,12) as 0.75GPa and 0.92GPa respectively while their shear strengths were 120MPa and 150MPa. These materials are then seen to be stronger in shear than in tension as the yield strength of this material under creep is about 13MPa compared to the classical range of 12-43MPa) for this material[13]. The creep failure of these materials is therefore due to slip owing to mass movement of body of atoms that may form slip jog within the crystallographic plane since the yield strength of these materials was exceeded.

5. CONCLUSION

This study established the mechanical properties of polypropylene and that reinforced with calcium carbonate nanofiller as a new material under various serving creep conditions. Also established was that creep process may be a strengthening process slip occurring when the material yield strength is exceeded causes creep failure of polypropylene matrix composites. Plastic deformation at strains above 0.01 resulted to strain- hardening or strain-strengthening that manifested as the increased area ratios and associated creep cold work.

Also established by this study is a computational model for evaluating the elastic modulus of polypropylene matrix based material and expressed in equation (6) as

$$E = 2.222\varphi^3 + 3.095\varphi^2 + 3.368\varphi + 2.091$$

Both the Halphin-Tsai and the Birintrup equations for elastic modulus of unidirectional fibre composites were confirmed to be appropriate for prediction of elastic modulus of nanofiller composites with polymer matrix.

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