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Effects of temperature on the compressive properties of extruded recycled unplasticized polyvinylchloride (uPVC) plastics under transverse compressive loading

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Abstract
Recycled plastics, over the years, are believed to be inferior to virgin plastics. In this work, the compression test on recycled and virgin unplasticized polyvinylchloride (uPVC) under transverse loading at different temperatures shows that recycled uPVC exhibits better rigidity for all the temperatures considered except at 40°C where a stress at yield of 0.5919MPa and 0.6131 MPa was recorded for recycled and virgin uPVC, respectively. Recycled uPVC shows poor dimensional stability at temperatures between 25°C and 85°C with great improvement at 100°C and 115°C (16.9760% and 22.8960%, respectively) as compared to strain at fracture of 37.1300% and 42.3910%, respectively for virgin uPVC. Recycled uPVC was found to be a reliable, and in some cases, a better alternative to virgin uPVC. Improvement in the mechanical properties of recycled uPVC can be achieved if greater attention is given to purity, homogeneity and previous history of the uPVC regrind.

Introduction

An estimated 100 million tonnes of plastics are produced worldwide each year. As of 2003, China accounted for the bulk followed by the United States of America [1, 2,3]. At the moment, the per capita consumption of plastics in Nigeria is among the lowest in the world [4].

However, the manageability of plastics wastes has created environmental problems. With the rapid increase in the generation of plastics wastes, disposal is made more difficult because most plastics resist decay so well that they take several years to breakdown naturally [5, 6].

In order to reduce these wastages and the health hazards they constitute, different waste disposal methods such as bio-degradation, pyrolysis, hydrolysis, incineration, land filling and recycling were developed. In all these methods, recycling is discovered to be the best method of waste disposal [7].

If recycled plastics are to be used in addition to or as an alternative to virgin plastics in transverse compressive loading conditions, their transverse compressive loading properties must show close similarity. This formed the basis of this research work.

The aim of this investigation is to determine experimentally, the effects of temperature on extruded recycled uPVC under transverse compressive loading condition as compared to extruded virgin uPVC. It would also provide manufacturers of extruded recycled uPVC products, data that could be of use in design considerations and in ascertaining the mechanical advantage in the use of recycled uPVC in addition to or as an alternative to virgin uPVC.

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Materials and Methods

Experimental Procedures

The compression test was conducted on a 50KN Testometric Universal Testing Machine (UTM). The compression test specimens were produced from extruded cylindrical virgin and recycled uPVC pipes (Kay Plastics Nigeria Limited, Ilorin). The specimens were produced from similar product batches of the extruded uPVC pipes. The recycled uPVC pipe used is a by-product of a single "primary" and "secondary" recycling process [8]. The uPVC regrind used for the production of the recycled pipes had not undergone any adverse exposure that could have any significant effect on its mechanical properties.

The dimensions conform to the American Society for Testing Method (ASTM) specifications for testing tubes [9]. Machining operation (turning between centers) was carried out on the lathe to reduce the pipe to the required external diameter. The turned pipe was then cut into required lengths (i.e. specimen height) using a hacksaw. Facing and finishing was carried out on the lathe to remove roughness caused by the hacksaw blades using a cutting tool and emery cloth respectively. Prior to heat treating and testing, the internal and external diameter and length of the specimens were measured. The average values were adopted for computation.

The test was carried out at a room temperature (26°C ± 2°C). This is in line with the ASTM standard, which stipulates that temperature range of 20°C to 30°C with standard tolerance of ± 2°C be adopted as room temperature [10, 11, 12]. Prior to testing, the specimens were conditioned at a temperature of 26 ± 1°C for over 40 hours [9]. In each case, two tests were carried out on separate specimens for each temperature considered with an exposure time of one hour in an electric oven.

The test machine was set to static mode and then activated to commence testing at a test speed of 1.30mm/min. Values of parameters of interest selected and inputted into the computer prior to testing was displayed including the stress-strain graph. The outside diameter of the specimen was inputted as specimen height.

Results and Discussion

Compressive Stress Versus Compressive Strain Curves

Figures 1a, 2a and 1b, 2b shows the compressive stress versus compressive strain curves for virgin and recycled uPVC, respectively. From the figures, it is observed that, except at 40°C where yield stress for virgin uPVC is greater than that of recycled uPVC (0.6131 and 0.5919MPa, respectively), recycled uPVC has greater values for stress at yield, ultimate and fracture points. This implies that recycled uPVC exhibits the greater rigidity (except at 40°C) and plastic deformation at ultimate and fracture points with increasing temperature. Figures 2a and 2b show that virgin uPVC exhibits improved plasticity while recycled uPVC shows improved rigidity from 85°C to 130°C.

These observations could be attributed to the presence of impurities in the regrind uPVC or the effect of previous exposure of the materials [13, 14]. The latter which is negligible in each raw material being recycled could have significant effect collectively on the mechanical properties of the recycled product.

Comparing Figures 1a; 2a and 1b; 2b, it is interesting to note that 85°C appears to be the transition point in the compressive properties of the two materials. This is due to the fact that 85°C is the softening temperature of uPVC [14]. At this temperature and beyond, plasticity is expected to increase due to improved mobility of the molecular chains in the structure of the uPVC, however, this is not the case with recycled uPVC. This discrepancy could be attributed to the fact that, though uPVC is amorphous in nature, commercial uPVC has small amount of crystallinity (about 5 – 15% depending on the thermal treatment) due to its syndiotactic nature. Crystallinity reduces the mechanical properties of uPVC [15]. In the case of recycled uPVC, crystallinity had been reduced considerably during recycling. This leads to random arrangement and interlocking of molecular chains. The latter causing restriction of movement of molecular chains at temperatures above 85°C, hence, improved rigidity and dimensional stability is exhibited even at high temperatures.

Compressive Stress and Compressive Strain Versus Temperature Curves

(i) Figure 3 shows the compressive stress at yield versus temperature curves for virgin and recycled uPVC. It may be seen that recycled uPVC exhibits greater rigidity at 25°C to 130°C, except at 40°C where yield stress is greater for virgin uPVC (0.6131 and 0.5919 MPa for virgin and recycled uPVC, respectively).

Figure 4 shows the compressive stress at ultimate point versus temperature curves for virgin and recycled uPVC. It may be seen that recycled uPVC has greater ultimate stress from 25°C to 130°C. This implies that recycled uPVC has greater rigidity at ultimate point for all the temperatures considered.

Figure 5 shows the compressive stress at fracture versus temperature curves for virgin and recycled uPVC. It may be seen that recycled uPVC shows greater rigidity prior to compressive failure from 25°C to 130°C.

The improved compressive properties exhibited by recycled uPVC could be attributed to the reduction in crystallinity of its molecular structure following the recycling process; hence giving rise to increased amorphousity and thermal rigidity, dimensional stability and reduced strain hardening at temperatures above softening temperatures of uPVC 85°C [8, 17].

(ii) Figure 6 shows the compressive strain at yield versus temperature curves for virgin and recycled uPVC. It may be seen that recycled uPVC exhibit greater plastic deformation at yield for all the temperatures considered.

Figures 7 and 8 show the compressive strain at ultimate and fracture point versus temperature curves, respectively, for virgin and recycled uPVC. It may be seen that recycled uPVC shows lower plastic deformation at ultimate and fracture point at 100°C and 115°C

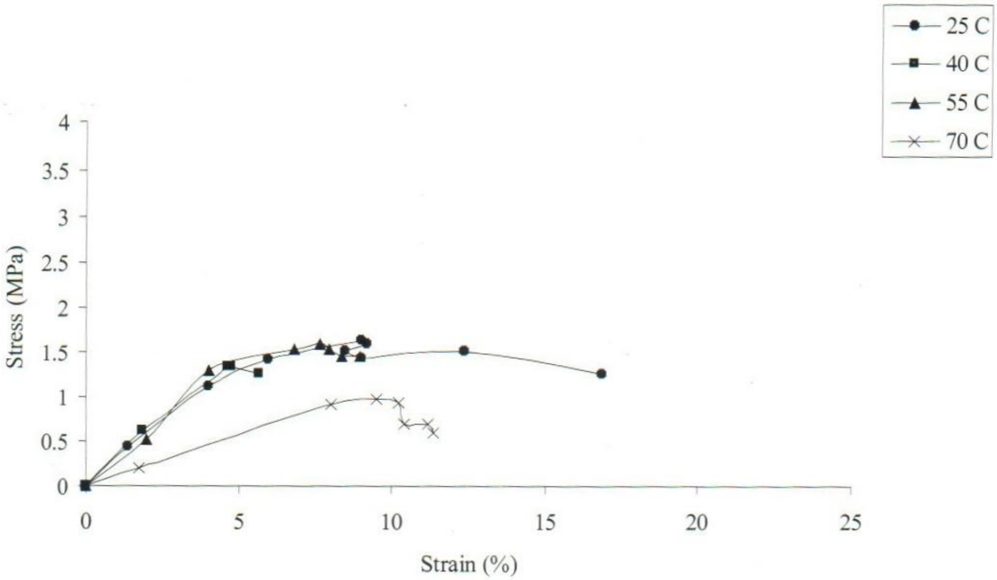

Figure 1a: Compressive Stress Versus Compressive Strain (Virgin) 25°C - 70°C

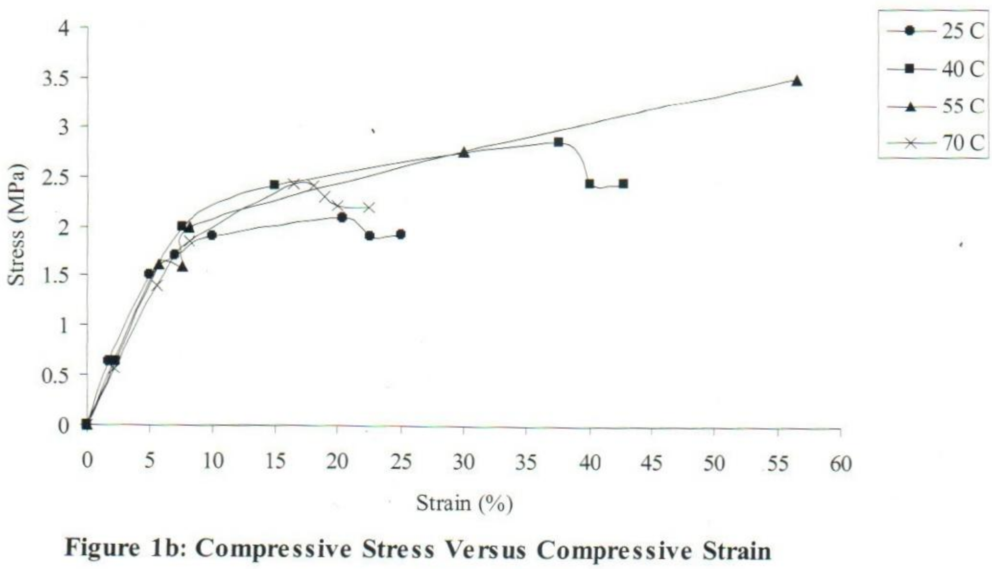

Figure 1b: Compressive Stress Versus Compressive Strain (Recycled) 25°C - 70°C

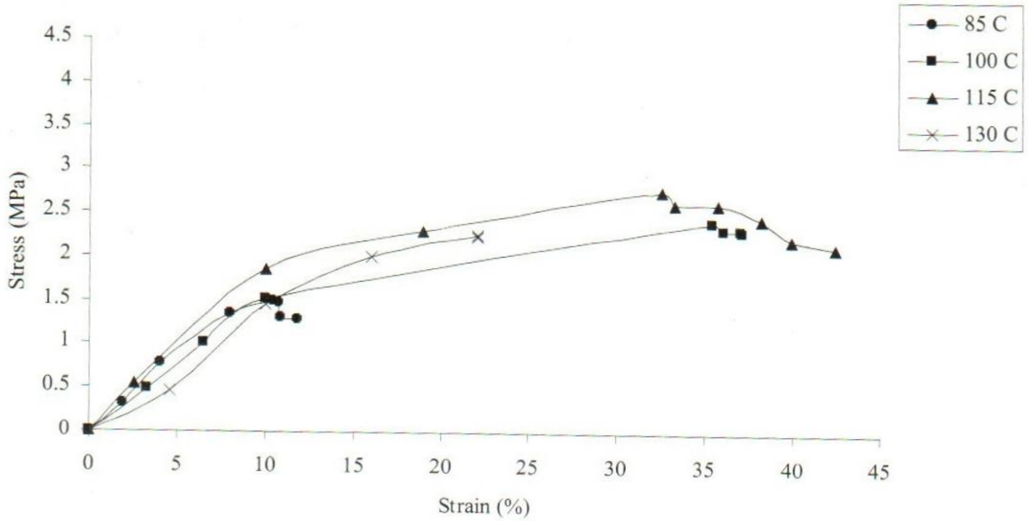

Figure 2a: Compressive Stress Versus Compressive Strain (Virgin) 85°C - 130°C

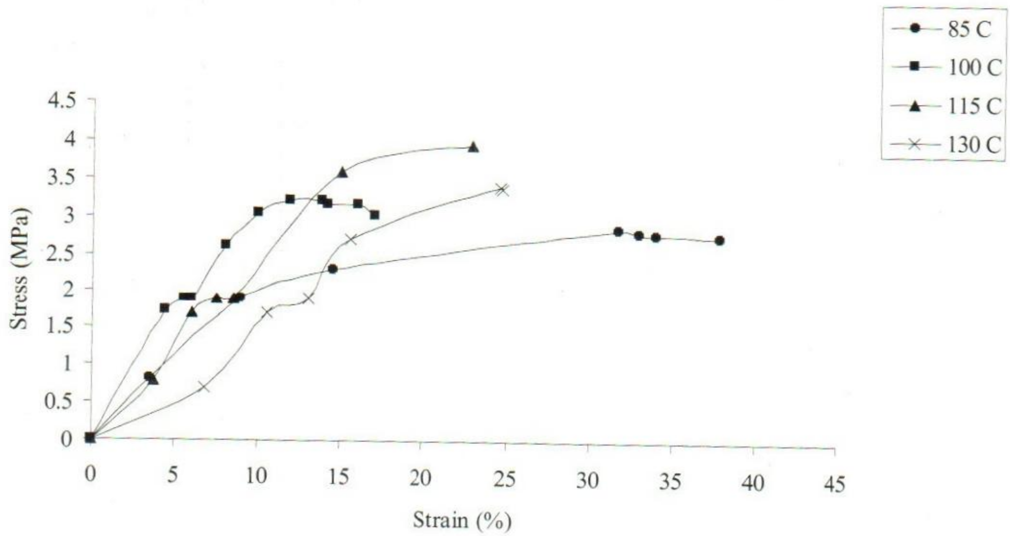

Figure 2b: Compressive Stress Versus Compressive Strain (Recycled) 85°C - 130°C

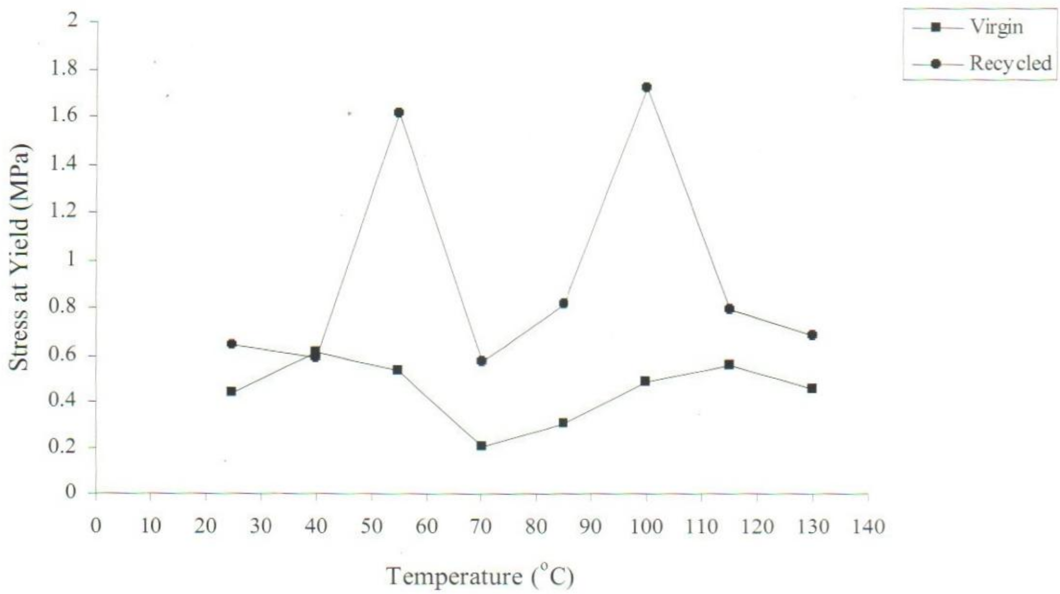

Figure 3: Compressive Stress at YieldVersus Temperature

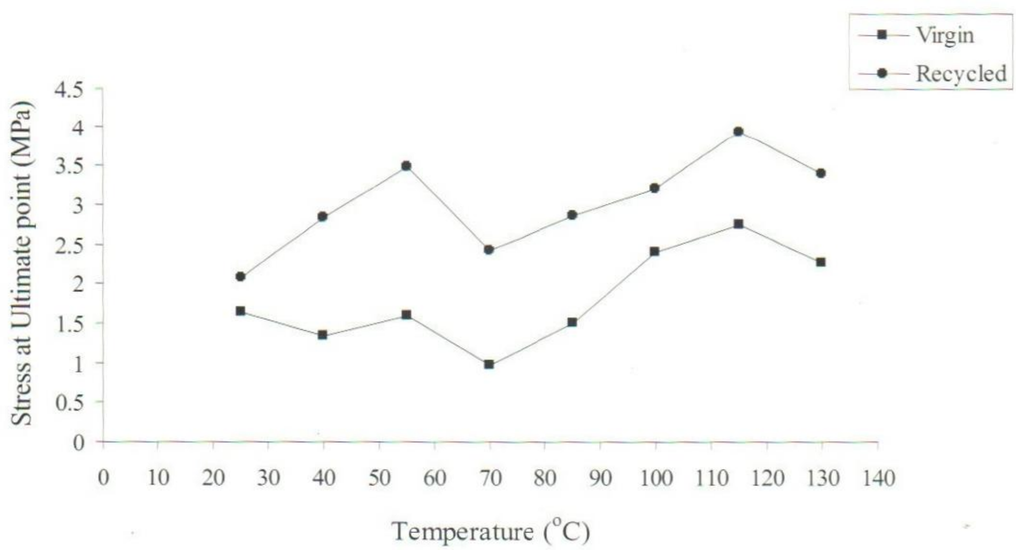

Figure 4: Compressive Stress at Ultimate Point Versus Temperature

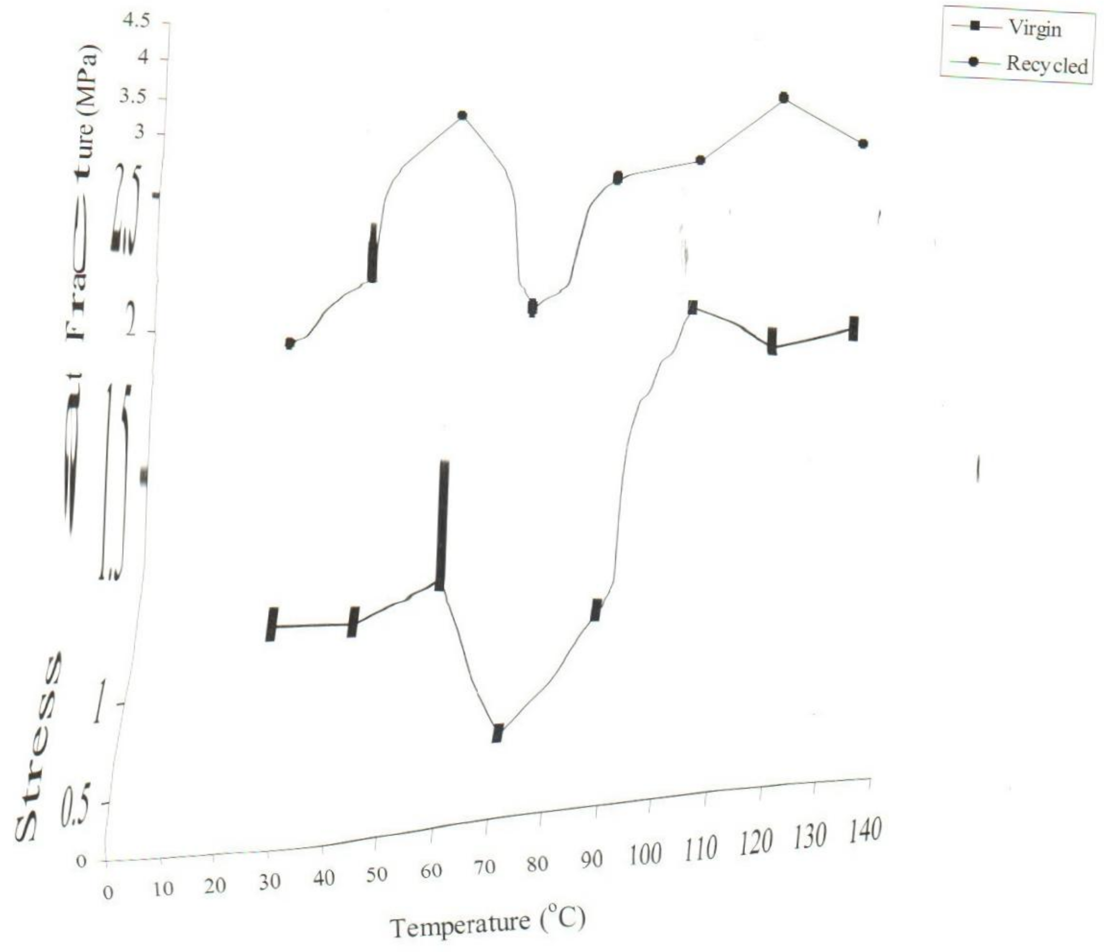

Figure 5: Compressive Stress at Fracture Versus Temperature

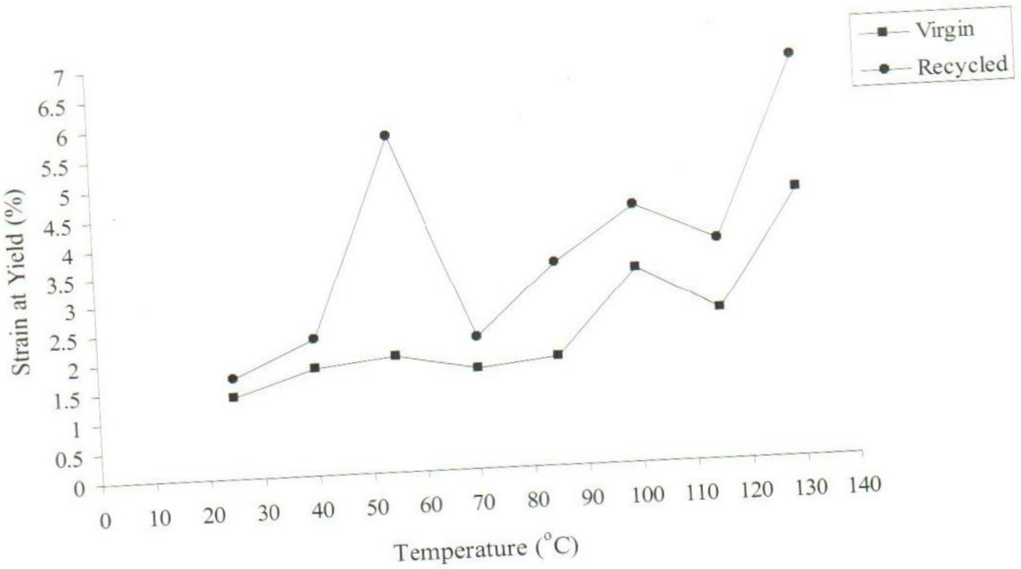

Figure 6: Compressive Strain at Yield Versus Temperature

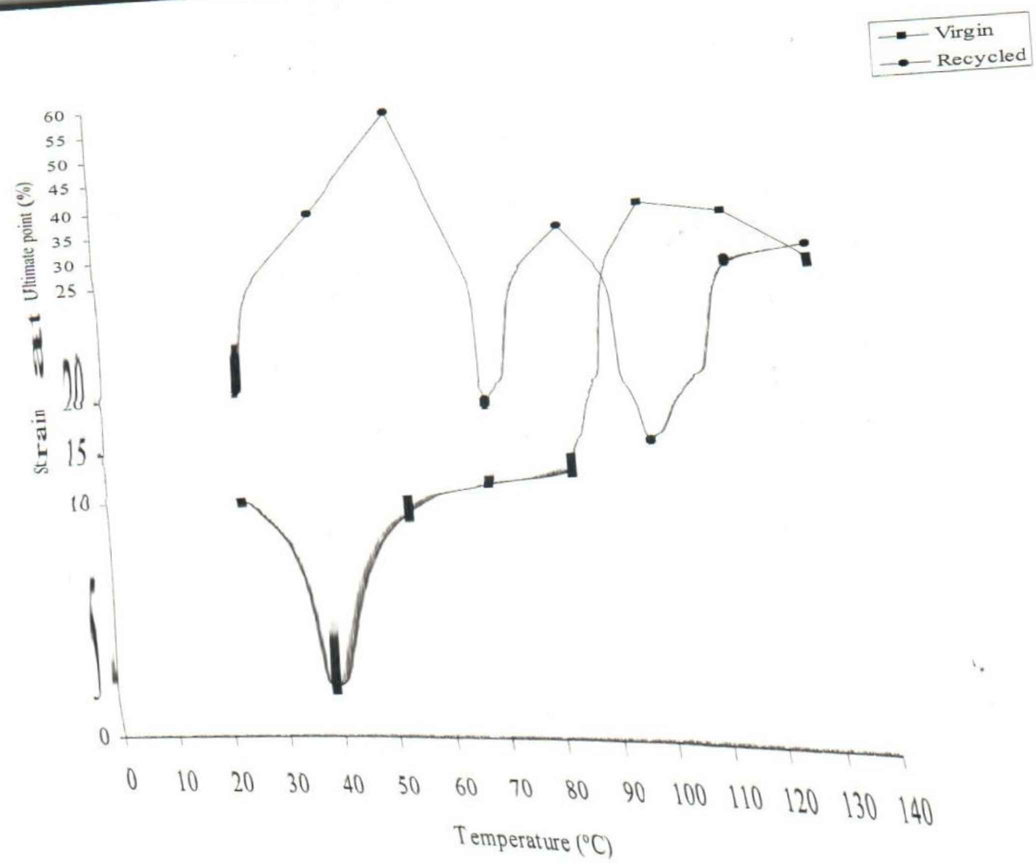

Figure 7: Compressive Strain at Ultimate Point Versus temperature

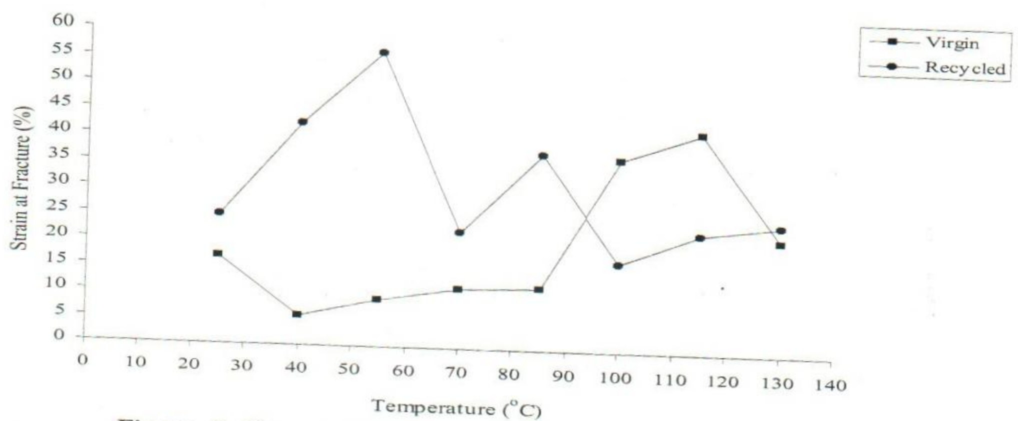

Figure 8: Compressive Strain at Fracture Versus Temperature

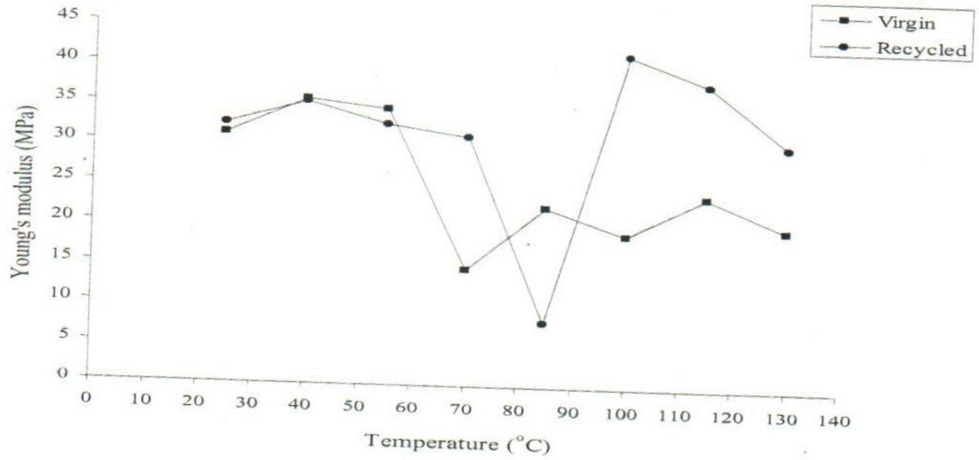

Figure 9: Young's Modulus Versus Temperature

almost equal strain at 130°C. This variation in strain at temperatures above 85°C may be attributed to the effect of the softening temperature on the compressive property of uPVC [14, 17). The sudden rise and later drop in strain for virgin uPVC is expected of uPVC;
increase in strain at temperature above 85°C and decrease in strain at temperatures approaching aly-activated temperature of 150°C [16]. In the case of recycled uPVC, a sharp drop occurs at 85°C and a gradual rise at increased temperature. This could be attributed to the presence of impurities, which cannot be totally removed, from the uPVC regrind and the collective effect of previous exposure of the uPVC [8].

Young's Modulus Versus Temperature Curve

Figure 9 is the Young's modulus versus temperature curves for compression test on virgin and recycled uPVC. It may be seen that at 85°C, recycled uPVC experienced a sharp drop in modulus [17]. This shows that the Young's modulus for recycled uPVC is greatly affected by the softening temperature of uPVC transitory to the dehydrochlorination temperature of uPVC plastics at 150°C [16].

Conclusion

It was found that, under compression (transverse loading conditions), recycled uPVC plastic is suitable;

(i) for rigidity, for all the temperatures considered except at 40°C where stress at yield is lower (0.5919 and 0.6131MPa for recycled and virgin uPVC, respectively).

(ii) for plasticity at 25°C to 85°C and 130°C.

Further work needs to be carried out to establish the validity of these results for uPVC regrinds with different history (physical, chemical or environmental) and injection moulded recycled uPVC

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