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FIBRAL FORMING SYNTHETIC POLYETHERS FROM ISOMANNIDE AND GROUP 4 METALLOCENE DICHLORIDES AND ORGANOTIN DIHALIDES

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ABSTRACT

Polymers were formed in moderate yield and chain length from the interfacial polymerization of isomannide and Group 4 metallocene dichlorides and organotin dihalides. These polymers possess a rigid backbone promoting the formation of fibrils. The polymers spontaneously formed flexible fibrils with aspect ratios of over 1000. The products were synthesized from commercially available materials, so reproduction should be straight forward.

KEYWORDS: Isomannide, Group 4 metallocene polymers, titanocene polymers, zirconium polymers, hafnocene polymers, organotin polymers, spontaneous fibril formation, interfacial polymerization.

INTRODUCTION

We have been engaged in the synthesis of a variety of metal-containing polymers including Group 4 metallocene and organotin-containing polymers for a variety of purposes. Most recently one focus is on the synthesis and characterization of polymers as anticancer, antiviral, antimould, and antibacterial agents.[1-37] We recently reported in this journal the formation of polymers from isomannide which exhibited good inhibition of a variety of human cancer cell lines.[7,8]

Isomannide (Fig.1) is a natural product originally derived from the secretions of the flowering ash, so it is a "green" material. Isomannide (CAS 641-74-7) has a variety of names including the IUPAC name (3*R*,3*aR*,6*R*,6*aR*)-2,3,3*a*,5,6,6*a*-hexahydrofuro[3,2-b]furan-3,6-diol. It is commercially produced from glucose in large amounts. Its structure is given in Fig. 1. It is also known as mannitol from its resemblance to the Biblical food. It is a sugar alcohol derived from sugar by reduction derived from the double dehydration of hexitols as mannitol. It is structurally similar to isoidide and isomannide. The selective dehydration of mannitol to isomannide occurs in good yield with the use of zeolite.[38] Pseudo-peptides derived from isomannide are inhibitors of serine proteases.[39] Clinically it is used to reduce acutely raised intracranial pressure after a head trauma until a more definitive treatment is prescribed.[40,41] It is also used to open the blood-brain barrier by temporarily shrinking the endothelium cells that make up the barrier thus is part of our effort aimed at combating brain cancer and other related brain related problems including Alzheimer's, dementia, amnesia, autism, epilepsy, stroke, Lupus, cerebral palsy, Parkinson's, etc. It is routinely used for delivering drugs to the brain.[40,41] It has other medical uses. In foods, is it employed as a sweetener for persons with diabetes.

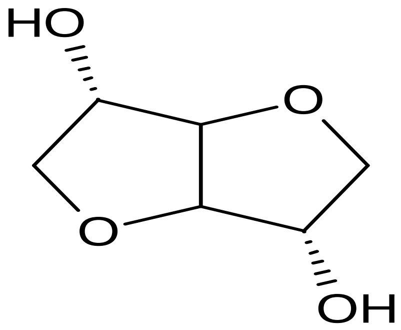

Figure 01: Structure of isomannide.

Isomannide offers rigidity and non-toxicity and is touted as a good intermediate for inclusion into polycondensation polymers. There has been some effort at including isomannide into polymers. A number of polyesters and polycarbonates have been prepared from isomannide.[42-50] Much of this effort has been reviewed. [42] For instance, Kricheldorf and coworkers produced a number of polymeric materials from reaction of isomannide with dialkylcarbonates, diphosgene, co-condensations of isosorbide and isomannide, producing a variety of polycarbonates.[42]

Some of the syntheses have been achieved employing the interfacial polycondensation of isosorbide bischloroformate with various diphenols.[51-53] Many of these products are cholesteric liquid-crystalline materials with interesting optical properties.

We recently reported in this journal the synthesis of polyethers from reaction of Group 4 metallocene dichlorides (Figure 2) and organotin polyethers (Figure 3) from reaction with isomannide.[7,8]

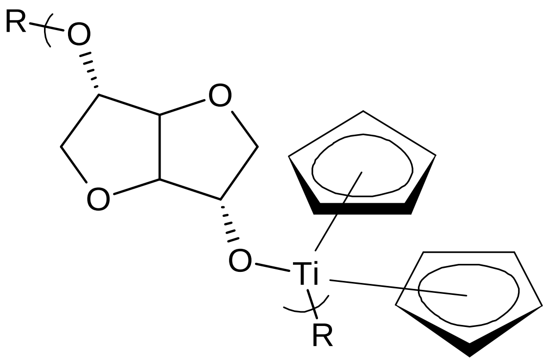

Figure 02: Structure of repeat unit from the reaction of Group 4 metallocene dichlorides, here titanocene dichloride, with isomannide. R represents simply chain extension.

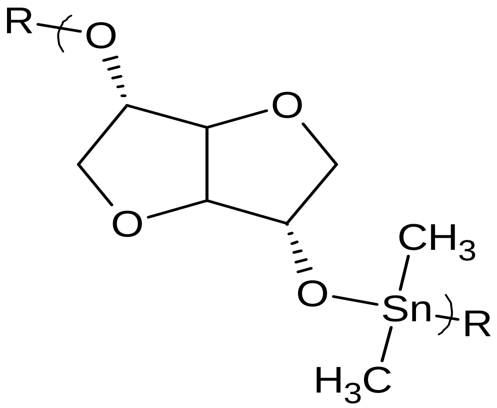

Figure 03: Structure of the repeating unit for the product from reaction of dimethyltin dichloride and isomannide where R represents simple chain extension.

EXPERIMENTAL

Reactions and Reactants

Reactions were carried out using the interfacial polycondensation technique such that the isomannide-containing phase and reaction are maintained under nitrogen because of the instability of isomannide to base in the presence of oxygen. Briefly, an aqueous solution (30 ml) containing the isomannide (0.00300 mol) and sodium hydroxide (0.0060 mol) was transferred to a one quart Kimax emulsifying jar fitted on top of a Waring Blender (model 1120; no load speed of about 18,000 rpm; reactions were carried out at room temperature, at about 25 ^{o}C). Stirring was begun and a heptane solution (30 ml) containing the organotin dihalide (0.00300 mol) or chloroform containing the metallocene dichloride (0.00300 mol) was rapidly added (about 3-4 seconds) through a hole in the jar lid using a powder funnel. The resulting solution was blended for 15 seconds. Dilute (0.1 molar HCl) is added to neutralize any remaining base. The nitrogen blanket is no longer necessary. The precipitate was recovered using vacuum filtration and washed several times with deionized water and heptane or chloroform to remove unreacted materials and unwanted by-products. The solid was washed onto a glass petri dish and allowed to dry at room temperature.

Titanocene dichloride (1271-19-8), isomannide (69-65-8), diphenyltin dichloride (1135-99-5), dibutyltin dichloride (683-18-1), and zirconocene dichloride (1291-32-3) were purchased from Aldrich Chemical Co., Milwaukee, WS; and hafnocene dichloride (12116-66-4, dioctyltin dichloride (3542-36-7), and dicyclohexyltin dibromide (2954-94-1).) were obtained from Ventron Alfa Inorganics, Beverly, Mass.; diethyltin dichloride (866-55-7) was obtained from Peninsular Chemical Res., Gainesville, FL. The reactants were used as received.

Physical characterization

Light scattering photometry was carried out employing a Brice-Phoenix Universal Light Scattering Photometer Model 4000. DMSO was the solvent. Infrared spectra were obtained employing attenuated total reflectance infrared spectroscopy utilizing a JASCO FT/IR-4100 fitted with an ATR Pro 450-s. Additional characterization including NMR and MALDI MS were was carried out but not reported in this paper. Results are reported elsewhere. [7,8] The fibrils were examined using an Olympus CH30 Microscope with variable magnification (x10-1000).

RESULTS AND DISCUSSION

Product Yield and Chain length

Polymerization occurs through the interfacial polymerization process developed by Morgan and coworkers at DuPont and enlarged by Carraher.[54-57] The interfacial synthetic technique is employed industrially in the production of aramid fibers and polycarbonates. The rapidity of the reaction is a consequence of at least two factors.[58,59] First, the activation energy between acid chlorides and alcohols is about 20 kcal/mol compared with the typical reaction between acids and diols of about 40 kcal/mol. Second, the rapid stirring enlarges the interfacial surface on the order of 10,000 times. The reaction is rapid being completed within 10 seconds.

Product yield and chain length are given in Table 1 for the overall product since the fibrils and platelet materials appear to be the same expect for the linear structure for the fibrils.

Table 01: Product yield and chain length, degree of polymerization, DP for the product of metallocene dichlorides and organotin dihalides with isomannide.

Metallocene/Organotin	Yield (%)	Molecular Weight	DP	% Fibril
Cp_2Ti	24	6.5×10^4	200	2
Cp_2Zr	52	5.9×10^5	1600	30
Cp_2Hf	50	2.0×10^4	45	4
Dimethyltin	50	2.6×10^4	80	0
Diethyltin	65	4.4×10^4	120	0
Dibutyltin	66	2.2×10^4	53	<1
Dicyclohexyltin	98	1.1×10^5	230	1
Diphenyltin	56	5.7×10^4	130	1

The product with the greatest percentage of fibril is from the zirconocene product which is reasonable since it is probably the most rigid since zirconium is about the same size as titanium yet more massive.

Infrared spectral results

Infrared spectra were obtained for the monomers and products (platelets and fibrils). The spectra for the platelets and fibrils were similar. Of interest is the M-O-R bands for the fibrils were stronger consistent with a greater bonding for the fibrils compared with the platelets.

Table 2 contains results of this spectroscopy emphasizing the bands associated with the metallocene or organotin moieties. All bands are given in wavenumbers. The OH associated bands are absent as expected because of the formation of the M-O linkage. CH bands associated with the metallocene and isomannide are all present in the products as are other bands associated with both monomers. M-O bands are found at 420 and 345 below the capability of the employed instrumentation. Various scissoring, wagging and stretching bands derived from isomannide are observed.[60,61] Bands derived from the metallocene are found associated with various stretching and modes.[6,13,15-22,24] Thus, IR is consistent with the formation of the ether band.

Table 02: Infrared spectral bands for titanocene dichloride, Isomannide and Metallocene polymers.

Band assignment	Isomannide	Cp_2TiCl_2	Cp_2Ti Polymer	Cp_2Zr Polymer	Cp_2Hf Polymer
OH St	3402				
CH St Arom		3103	3110	3101	3100
CH Sym St Alip	2992,2958		2953, 2926	2954, 2925	2956, 2920
CH Assym St Alip	2891		2853	2851	2851
CH_2Scissor	1468		1486	1484	1490
Cp C-C St		1440	1441	1442	1440
CH_2 Scissor	1412		1414	1417	1396
C-C St		1371	1370	1374	1375
Def Scissor OH, CH	1197				
CO St in CHOH	1083		1080	1086	1086
CH ip Wag		1014	1011	1086	1014

Table 02: Infrared spectral bands present in the Monomers and Polymers associated with the Dibutyltin and Diphenyltin polymers.

Band Assignment	Isomannide	Bu_2SnCl_2	Bu_2Sn Polymer	Ph_2SnCl_2	Ph_2Sn Polymer
OH St	3402				
CH St Arom				3068,3051	3064,3046
CH Sym St Alip	2992,2958	2960,2927	2963,2953, 2929		2990,2951,
CH Asy St Alip	2891	2872,2858	2871,2856, 2804,2792		2871
SnPh St				1480	1481
CH_3 Sym St		1463	1465		
CH_3 Sym St		1380	1376		
CH_2Scissor	1412		1417		1428
Scissor OH,CH	1197				
Sn-O-C			1014		1022
CO St CHOH	1083		1081		1080
Ring Breath				996	997
CH_3 Rock		878	881		
Sym OP Bend Ring H				729	719
Asy OP Bend Ring H				691	691
SnC Asy St		592	594		
SnC Sym St		509	514		

The absence of the OH stretch in the polymer structures is consistent with bond formation linkage between the organotin moiety and isommanide. Bands are found in the range of 3360 are due to included water. Formation of a new band about 1016 is assigned to the Sn-O-C group is also consistent with linkage between the organotin moiety and isomannide. This band is found at 1014 for the dibutyltin product; at 1022 for the diphenyltin product; 1014 for the dichclohexyl product and 1016 for the dimethyltin product. Presence of bands characteristic of isomannide including various stretch, scissoring, and wagging bands in all polymers is consistent with its inclusion within the polymer structure as are the presence of bands characteristic of the organotin moiety in the polymers. Thus, infrared spectroscopy is consistent with the proposed formation of the organotin polyether with isomannide. Band assignments from isomannide[40,41] are consistent with those given in the literature as are assignments for the organotin.[7-9,42-47]

Isomannide IR spectral assignments are taken from literature.[54,55,59] Metallocene IR assignments are also taken from literature.[13,15-22,24] as were the organotin assignments.[7,11]

Fiber formation

We have observed instances where the metal-containing polymers spontaneously form fibrils. This occurs when the polymers themselves are stiff. We initially reviewed this tendency for a number of Group 4 polyester over three decades ago.[6] Briefly, the polymers were formed employing the interfacial polymerization process. The product precipitates from reaction, collected on filter paper in a Buchner filter with suction, washed with the organic solvent and water to remove unreacted materials and salts, and subsequently washed into a glass Petri dish using acetone to remove the product from the filter paper. The product is allowed to dry. Some of these produced fibrils when they were scraped from glass Petri dishes. As the product is recovered from the dish, fibrils are spontaneously formed. The fibrils appear as the polymer is scrapped, using a flat-ended steel spatula. It appears that the mechanical agitation is sufficient to induce fibil formation. This is the case here.

Most of the fiber-forming structures contain rigid backbones as is the case with the isomannide products shown in (Figures 2 and 3).

Following are pictures and partial descriptions of the fibrils. The titanium-containing products are generally red-cream colored because of the presence of the Ti-Cp color group. The fibrils are about 0.3 cm long and 10^{-2} to 10^{-3} mm thick giving an aspect ratio, length to thickness, of about 3000 to 30000 well within the recognized fiber range (Figure 6). The percentage of product that was fibrous was about 2%.

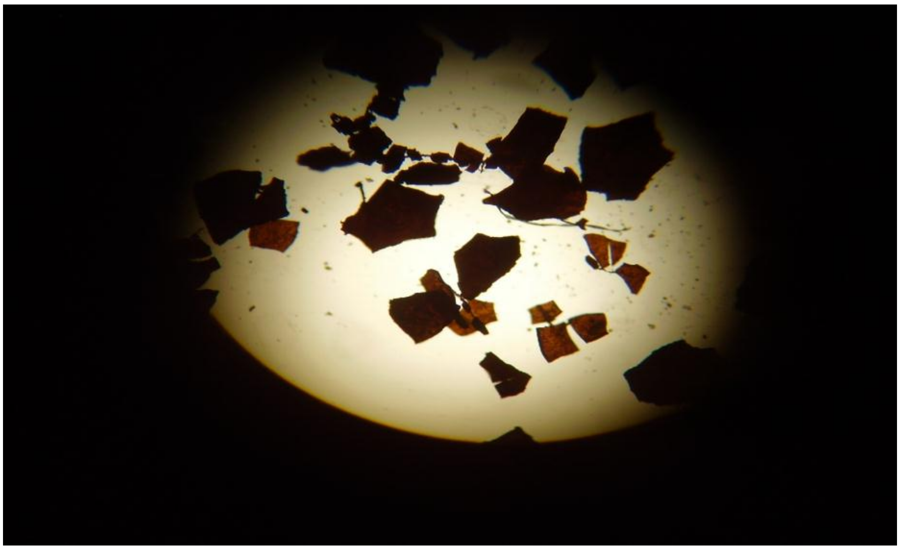

Figure 04: Picture of the titanocene polymers.

Figure 5 contains a picture of the zirconocene products featuring white fibers of about 0.1 cm in length and 10^{-2} thickness giving an aspect ratio of about 1000. About 30% of the product appeared to be fibrous.

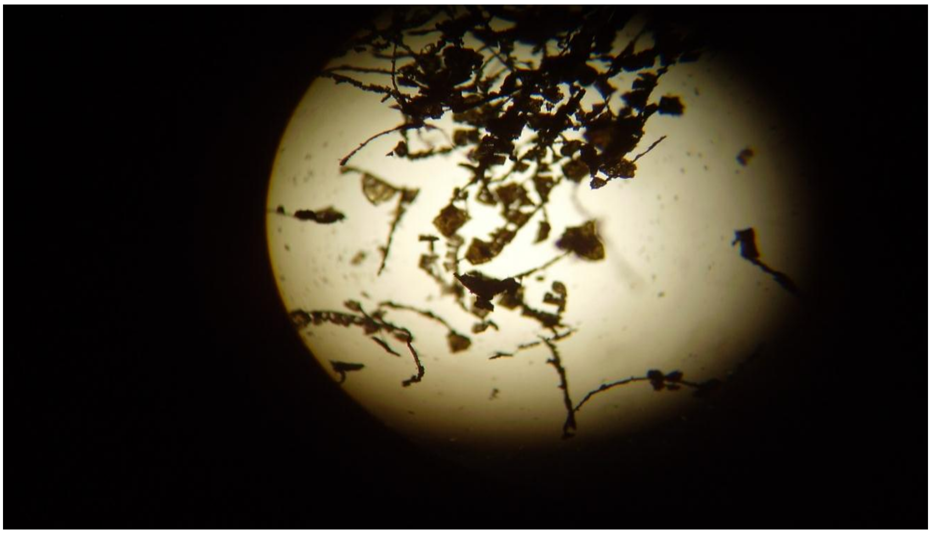

Figure 05: Picture of the white zirconocene product at 10-fold magnification. The fibers appear to possess spurs radiating off the main trunk. The non-fibrous material appears as platelets.

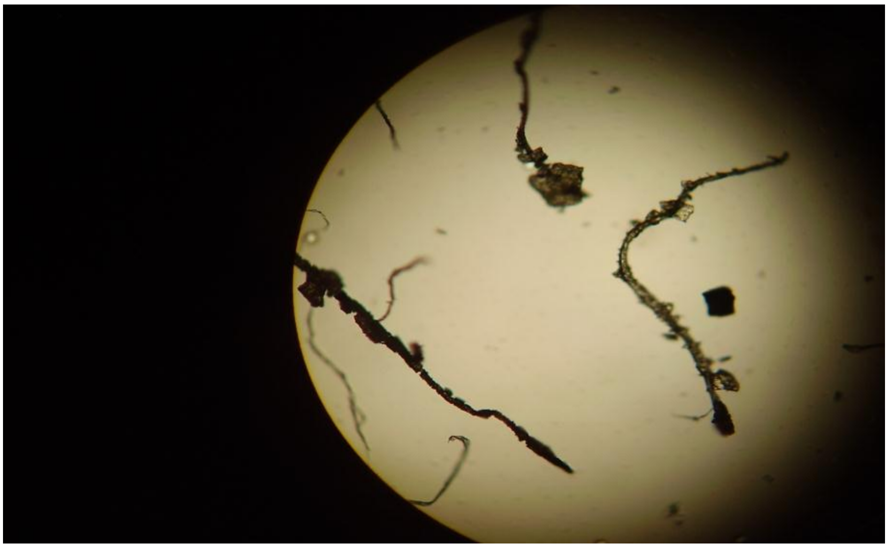

Figure 06: Picture of the zirconocene product at 40-fold magnification.

The fibrous material forms ball-like structures with the spurs acting to hold the ball together (Figure 7). The balls are flexible and can be held by hand retaining the general geometry and flexibility after compressing them by hand.

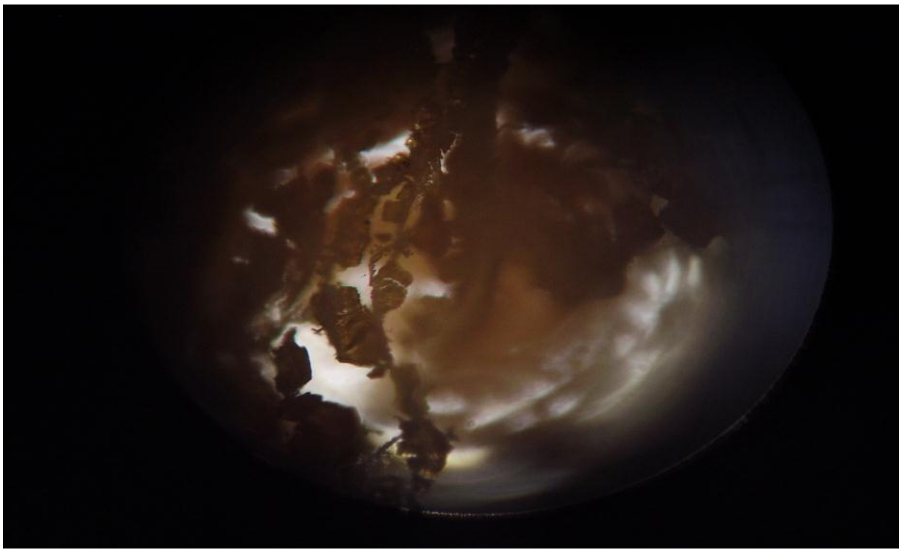

Figure 07: Picture of a ball-like structure of the zirconocene polymer. The ball had a radius of about 1.5 cm.

Figure 8 contains a picture of the materials from the hafnocene polymer.

Figure 08: The hafnocene product had white fibers about 0.1 cm in length an aspect ratio of about 1000. The fibers appear to hold the flat plates together.

Some of the products from organotin reactants produced fibrils. These were those from dibutyltin dichloride, diphenyltin dichloride and dicyclohexyltin dichloride. All of the products formed fibrils similar to those to the metallocenes with aspect ratios of about 1000. The fibers were about 0.1 cm in length and about 10^{-2} cm thick. As in the case of the metallocene derived products, the fibrils appear to hold together the platelets. Representative pictures appear following.

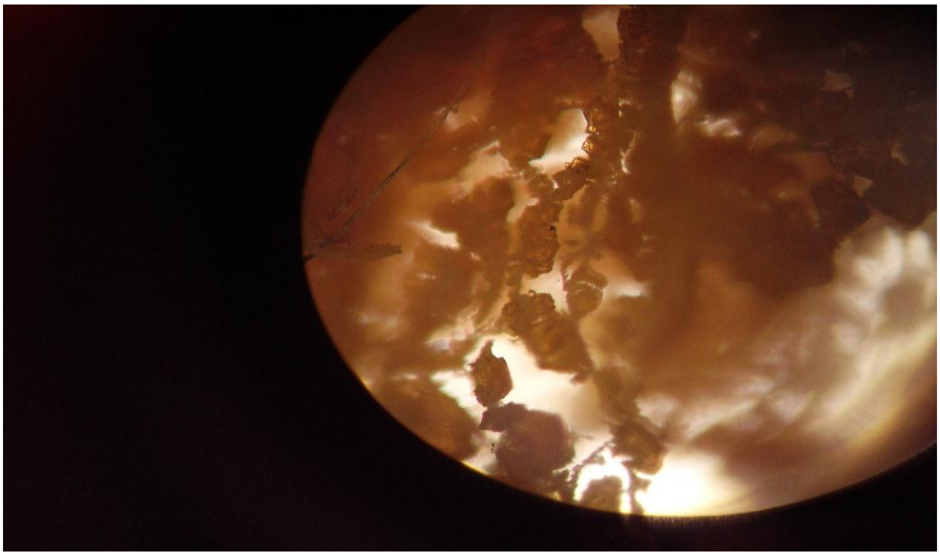

Figure 09: Picture of fibrils from the product of dicyclohexyltin dichloride and isomannide.

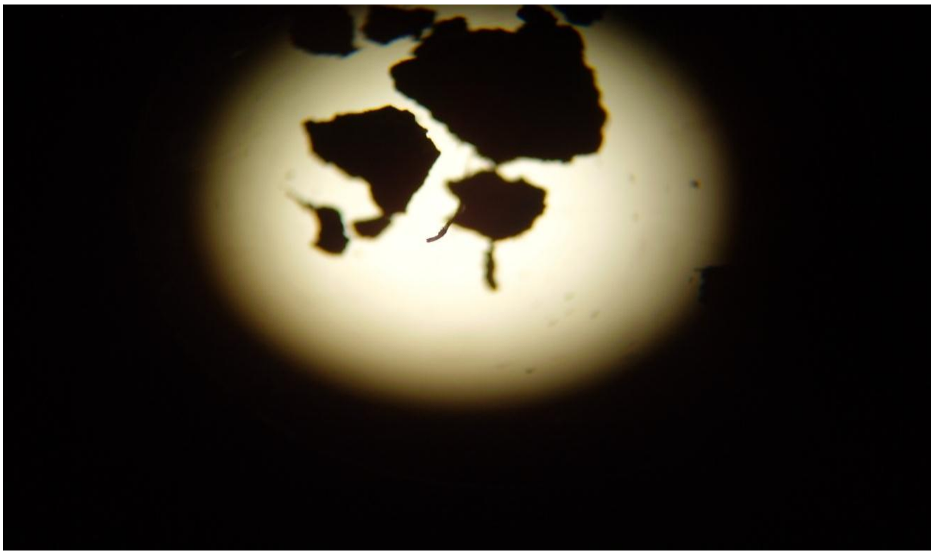

Figure 10: Picture of fibrils from the product of diphenyltin dichloride and isomannide.

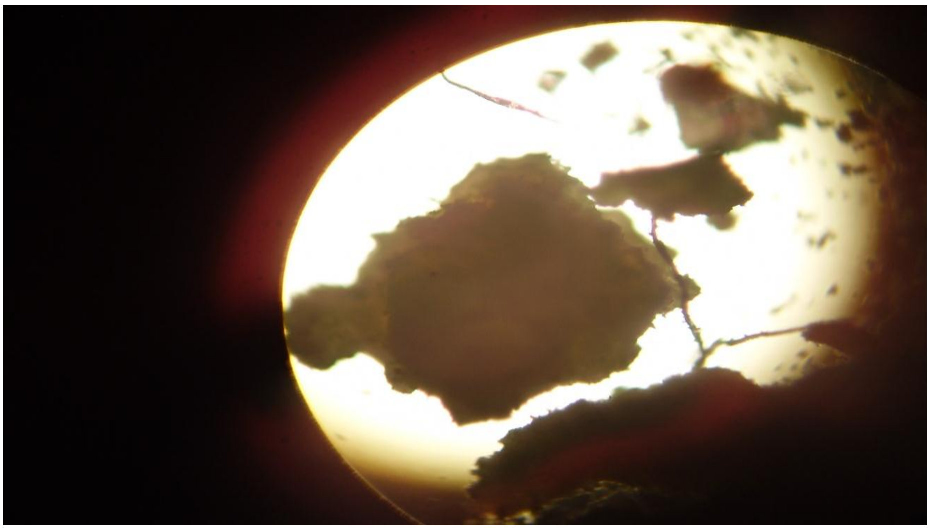

Figure 11: Picture of the product from diphenyltin Dichloride and Isomannide.

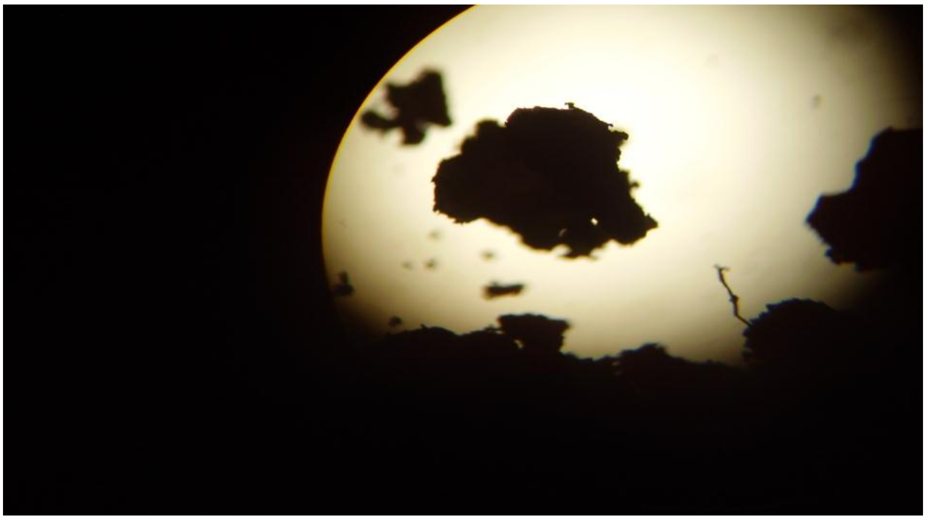

Figure 12: Picture of the product from dibutyltin dichloride and isomannide.

The most obvious area of application is as fibers for composites. There are a number of metallic whiskers that are employed as high strength fibers in composites.[58-60] These composites are among the strongest known composits. The mechanical and electrical properties of the fibers need to be studied. It is possible that the fibers are semiconductors to near conductors allowing their use as directional electrical wires. Many polymers of similar structures are semiconductors. Much work needs to be done to further investigate the differences between the fibers and non-fibers and their properties. This is being done by others. A further discussion of the fibrils is given elsewhere. A general review is found in the literature of these metal-containing fibers and their potential uses.[61]

SUMMARY

Polyethers have been produced by the interfacial polymerization of Group 4 metallocene dichlorides and organotin dichlorides with isomannide in moderate yield and chain length. Synthesis rapidly occurs through use of the interfacial polymers. The interfacial polymerization process is employed industrially to produce polycarbonates and aromatic nylons using commercially available reactants. Thus, ready synthesis to produce gram to kilogram amounts is reasonably straightforward. Structural characterization was accomplished using NMR, IR, MALDI MS (only IR data is presented here) and is consistent with the proposed polyether structure. The products spontaneously form fibrils. These fibrils are clearly visible to the eye and can be easily manually manipulated.

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