Studies of processing properties of PVC/wood composites

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Introduction

Current great interest of polymer composites is a result of prospecting for a new alternative for conventional engineering materials [1]. Despite the fast development of composite processing technology an explicit definition of a composite is not available in literature [1÷3]. The authors of *Powszechna Encyklopedia PWN* define composite as (Latin. *compositus* "complex") material consisting of at least two components (matrix and reinforcement) so chosen that each of them maintaining their own properties, improve properties of the composite and/or give it a new (additional) one [4]. The above-mentioned definition presents the main aim of new composites creating; describes the possibility to design properties of a final product, determined by kind and content of individual composite components [1, 2] and processing conditions [5].

Creating of composites is one of the physical methods of polymer modification which allows to improve of mechanical and processing properties as well as thermal or chemical resistance with possibility of cost reduction. Introduction of wood particles into polymer matrix is promising and dynamically developing method of thermoplastics modification. Wood-polymer composites have competitive properties to both wood and thermoplastic polymers. Low density, low values of frictional properties, biodegradability as well as relatively low cost are the advantages of wood while its drawbacks are compensated by properties of polymer matrix. Therefore, final products of WPC are characterized by interesting constructional and practical properties. Such materials can be applied as wood substitute in conditions where the products are exposed to frequent or permanent contact with water for example in construction, automotive, garden architecture [6, 7].

Thanks to the connection polymer materials with natural biodegradable wood, WPC are considered as ecological products, especially when both wood and polymer are derived from recycling. Moreover it is worth to emphasis the possibility to reprocess of wood-polymer composites [8÷10].

Good quality products of WPC can be made from Technological waste of PVC which is not always possible to use in processing [11, 12]

The aim of work

The aim of presented work was to determine the influence of processing temperature of polyvinyl chloride and its blends with wood filler (PVC/WF) on characteristics of both injection molding and extrusion processes as well as on selected mechanical properties of obtained materials.

Materials

The dry blends based on polyvinyl chloride S-58 (ANWIL S.A.) have been used in these investigations. Compositions contain stabilizers and internal lubricants system facilitating processing of PVC/wood composites. Pine flour, fraction 0.25-0.5 mm obtained in Polymer Technology Department of University of Technology and Life Sciences has been applied as a wood filler.

Methodology

Granulate preparation

PVC dry blend has been extruded using single-screw extruder T-32 (Metalchem-Gliwice). Screw L/D ratio equaled 28 (D=32 mm) and screw revolutions were 9 min^{-1}. The temperature of extrusion process has been controlled at four independent heating-cooling areas of extruder and two independent areas of head. Extrusion head with nozzle which L/D ratio equaled 30/5 has been used. Processing has been carried out with stable temperature in plasticize system of extruder equaling respectively 140°C, 150°C, 160°C, 170°C, 185°C. Extrudates obtained during the processing under the above-mentioned temperatures have been grinded in an impact mill. The material prepared in such a way as well as its blends with wood flour, dried for 3 h at 105°C and introduced to PVC in amount of 30 wt.% directly before processing, have been used in the following investigations.

Investigations of extrusion process

Grinded PVC and its blends with wood flour have been processed in single-screw laboratory Brabender extruder. Temperature has been regulated at two heating areas on the cylinder and at one area on the cylinder-head connector. The extrusion process has been carried out in the temperature ranging 140°C÷185°C that corresponds to the temperature of PVC granulates preparation. The head with rectangle cross section equaling 10 mm x 4mm and length equaling 130 mm with Teflon covered internal surface has been used. Such type of a head allows to form a profile and its calibration simultaneously. Temperature of this head depended on processing temperature and was decreased with increasing distance from cylinder-head connector. For various processing temperatures it equaled respectively (processing temperature/beginning of head/end of head): 140°C/103°C/93°C, 150°C/112 °C/98°C, 160°C/120°C/104°C, 170°C/125°C/110°C, 185°C/129°C/114°C. Screw rotation speed equaling 20 min^{-1} has been established by the use of trial and error method. During extrusion process torque (M_{obr}), pressure before head entrance (P) and extrusion output (W) has been measured. Obtained profiles have been used in investigations of mechanical properties.

Investigations of injection molding process

The characteristics of injection molding process of both PVC and its blends with wood flour have been done using injection molder Wh 80 Ap. The temperature of cylinder and nozzle was corresponding to the temperatures of PVC granulates preparation, as in the case of extrusion. The injection into mold form, which dumbbell shape was in accordance with the standard PN ISO 527, as well as into Archimedean spiral shape mold form has been conducted.

In the case of normalized sample injection the following parameters have been used: injection time: 5 s, time of holding pressure: 0.3 s, cooling: 78 s, screw revolution: 110 min^{-1}. The temperature of mold form equaled 75°C. The longitudinal processing shrinkage of normalized moldings has been measured. The investigation has been carried out 48 h after processing with 0.01 mm accuracy. Furthermore, mechanical properties of samples prepared in such a way have been studied.

In the case of spiral form the injection point was placed on its center. The depth and width of arm canal equaled respectively 1.7 mm and 6 mm. Mold was cooled to 17°C using water. Molding of spiral shape molded pieces have been carried out with following parameters: injection time : 2 s, time of holding pressure: 0.5 s, cooling: 42 s, screw revolution; 110 min^{-1}. The length of obtained spiral has been measured specially prepared measure.

Determining of mechanical properties

The normalized dumbbell shape samples and samples cut out from extruded profiles have been used in the investigations of selected mechanical properties. Mechanical properties have been determined during static extension by the use of universal testing machine TIRA test 2200. Research conditions were following: extension speed: 10 mm/s, distance between grips: 100 mm. Tensile strength (σ_M) and relative elongation at break (ε_B) have been measured. Charpy impact tests have been made in accordance with standard PN-ISO 179-1 using plain impact of pendulum with energy 4 J. Length, width and height of samples equaled respectively 80 mm, 10 mm, 4 mm.

Results

Extrusion

PVC granulates do not cause any problems during extrusion at any above-mentioned processing temperatures applied. Output of extrusion slightly decreases with increase of processing temperature (Fig. 1). Contrary behavior can be observed in the case of composites extrusion. Despite twelve-times decreased extrusion output in comparison with un-filled matrix processing efficiency increases from 0.6 g/min (140°C) to 1.9 g/min (185°C).

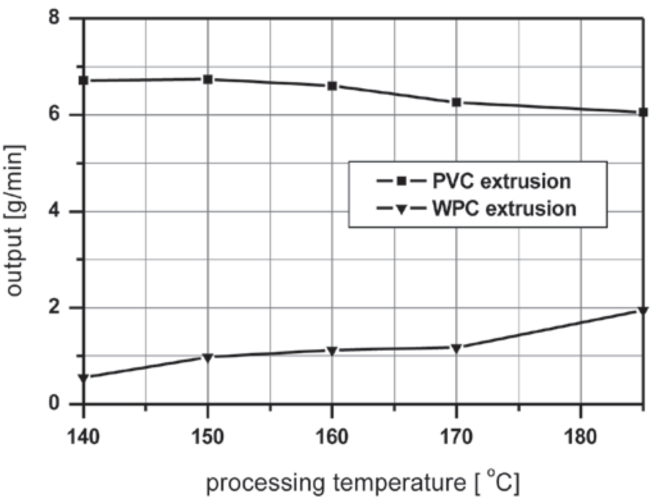

Fig. 1. Influence of processing temperature on extrusion output of PVC and PVC/WF composites

The increase of processing temperature results in pressure decrease before head entrance for both PVC and PVC/WF composites extrusion (Fig. 2). Polymer matrix filling by the use of wood particles contributes to an increase of viscosity and flow resistances of melted composites through the nozzle. That shows extrusion pressures. The highest difference between them has been observed for processing temperature: 185°C. Extrusion pressure for PVC and PVC/WF composites equals respectively 3.4 MPa and 19.3 MPa. In the case of PVC/WF composites drop of pressure with processing temperature increasing is smaller (31%) in comparison with PVC (86%).

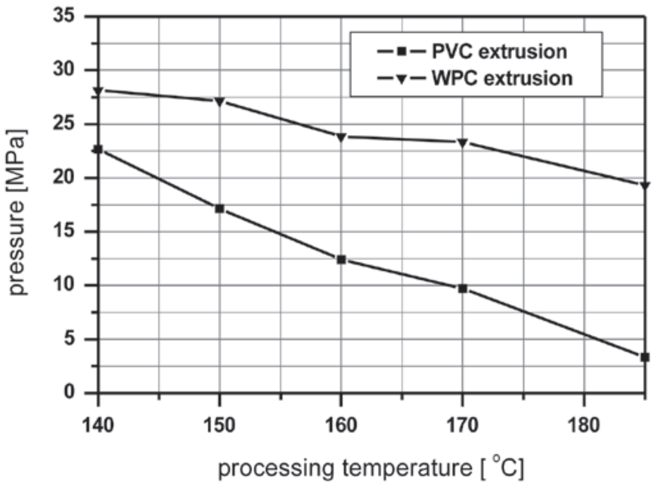

Fig. 2. Influence of processing temperature on plastic pressure before the nozzle entrance during extrusion of PVC and PVC/WF composites

Furthermore, the relationships between processing temperature and screw torque presented in Figure 3 confirm above-mentioned changes of pressure, viscosity and flow resistance values. In the case of PVC/WF composites extrusion at 140°C a two-times higher torque (28.5 Nm) is observed in comparison with PVC (13.4 Nm).

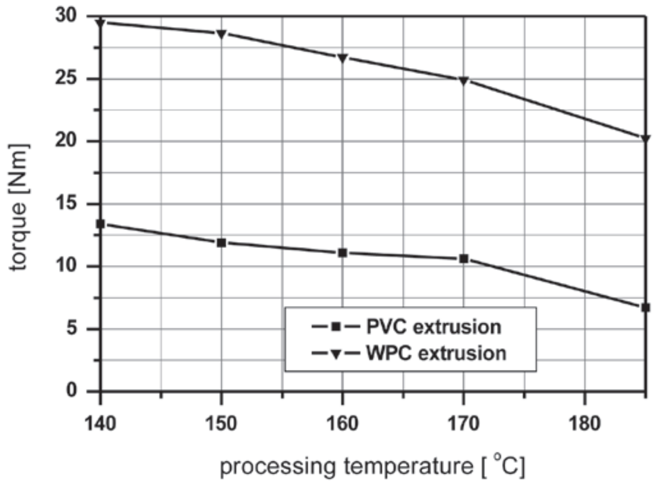

Fig. 3. Influence of processing temperature on torque extruder engine during extrusion of PVC and PVC/WF composites

Injection Molding

The measurements of spiral length show the influence of wood flour introduction into PVC matrix on the ability to mold form filling. As it was mentioned above, introduction of wood particles results in an increase of flow resistances in processing tools. It is also proved by decrease of composite spirals length even up to 53% in comparison with spirals of pure polymer obtained at 150°C. Increase of processing temperature significantly improves the ability of the material to fill the mold form, as presented in Figure 4.

Figure 5 presents relationship between linear shrinkage (S_L) and processing temperature. Shrinkage has been measured on the basis of PVC and PVC/WF samples length. Since polyvinyl chloride has low crystallinity degree, the value of linear shrinkage is not considerable. However, an extrusion temperature increase from 140°C to 185°C results also in the decrease of S_L value by 26.5%.

The complement of shrinkage loss of the material being cooled, occurs during holding pressure. It lasts until capillaries will have solidified. Therefore, injection molding at temperature 185°C and, in consequence, extended cooling time of PVC allows to improve transfer of the pressure compensating shrinkage value [13]. Additionally, increase of processing temperature causes an increase of PVC gelation degree and elasticity simultaneously [14] which better fills the mold form. Introduction of wood flour into PVC matrix significantly influences the decrease of the shrinkage but this changes practically do not depend on processing temperature.

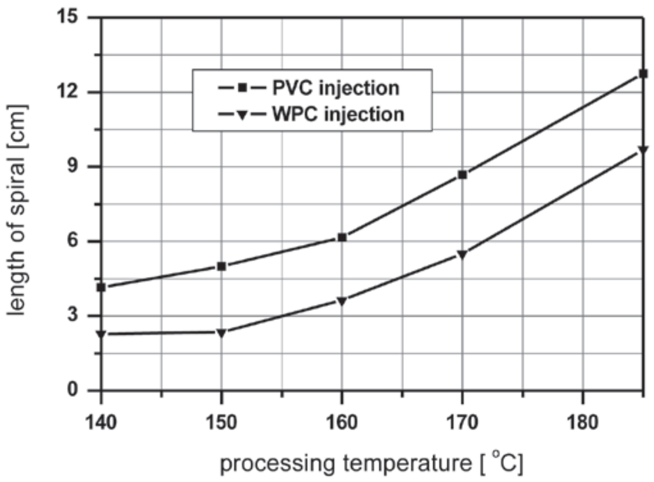

Fig. 4. Influence of injection temperature on the length of obtained spiral for PVC and PVC/WF composites

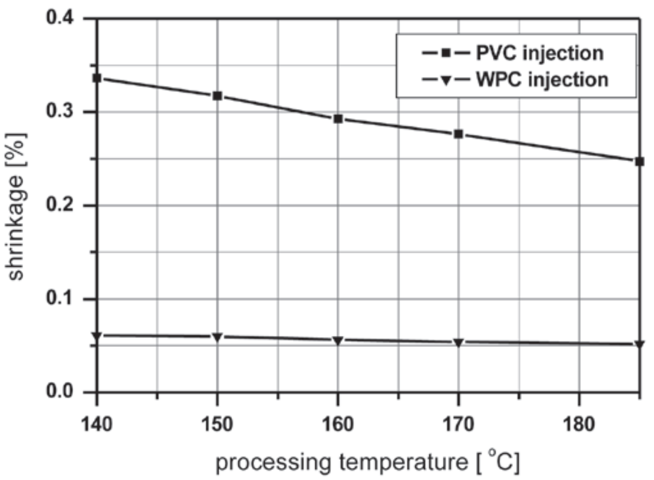

Fig. 5. Influence of injection temperature on the linear shrinkage of PVC and PVC/WF composites normalized molded pieces

Mechanical properties

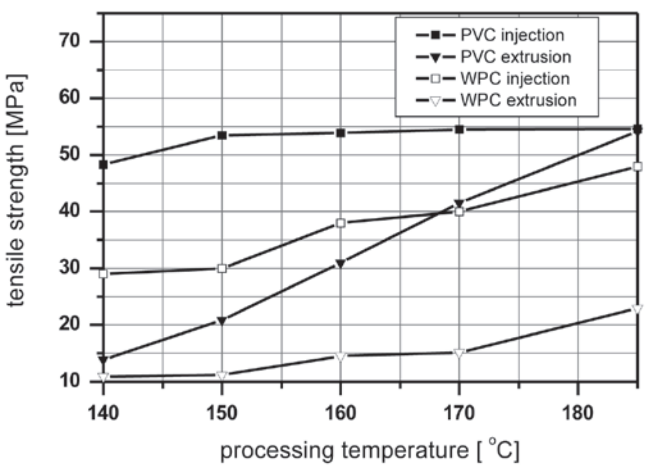

Fig. 6. Influence of processing temperature on tensile strength of PVC and PVC/WF composites obtained by injection molding and extrusion method

Improvement of PVC gelation degree, being an effect of increase of processing temperature, has an influence on the increase of tensile strength of both PVC and its composites (Fig. 6). The increase of extrusion temperature from 140°C to 185°C improves tensile strength of PVC samples from 13.9 MPa to 54.4 MPa. Tensile strength of extruded profiles is similar to the strength of molded pieces only for samples obtained at 185°C.

Tensile strength of PVC normalized samples injected at temperature 140°C is considerably lower from these obtained at higher temperatures. The difference of strength between samples obtained at temperature 150°C and 185°C is not so significant. Introduction of wood flour into PVC reduces mechanical properties of composite in comparison with un-filled matrix. The increase of processing temperature of PVC/WF improves σ_M value even by 90%. It is worth to notice that a kind of composite processing has significant influence on its tensile strength. Composite moldings demonstrate much higher tensile strength than extruded profiles even at the highest processing temperature applied.

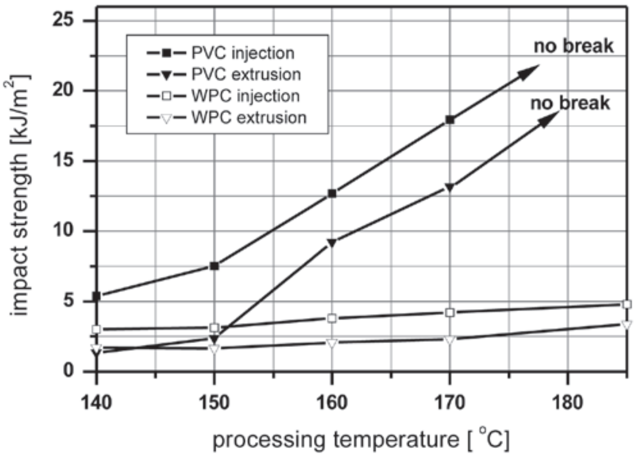

Fig. 7. Influence of processing temperature on the impact strength of PVC and PVC/WF composites obtained by injection molding and extrusion method

The increase of processing temperature also improves impact strength of both PVC and PVC/WF composites. Nevertheless, the improvement is much intensive for un-filled polymer. Molded pieces and extruded samples from PVC obtained at 185 °C do not break during the tests. Moreover, decrease of impact strength with addition of wood filler into polymer matrix can be observed independently of processing method applied.

Conclusions

The increase of processing temperature improves mechanical properties of PVC and PVC/WF composites obtained during both extrusion and injection molding processes. Polyvinyl chloride and its composites processed by injection molding method are characterize by better values of mechanical properties. This changes result from the increasing of PVC gelation degree [14, 15]. The investigations results of extrusion and injection molding processes illustrate what kind of problems potential producers of WPC composites with PVC matrix may expect. Thus, the conducted research indicates that application of dry blend with proper content enables processing of PVC/WF composites in whole range of temperature proposed above by the use of classical processing tools.

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W 1972 roku na Wydziale Technologii Chemicznej Wyższej Szkoły Inżynierskiej został powołany Zakład Technologii Chemicznej Powłok Ochronnych. W początkowym okresie zajęcia dydaktyczne były prowadzone przez specjalistów z Instytutu Mechaniki Precyzyjnej w Warszawie. Pierwsi absolwenci ukończyli specjalizację powłok ochronnych w 1974 roku. W 1976 roku, nastąpiło połączenie z Zakładem Chemii Nieorganicznej i utworzenie Zakładu Chemii Nieorganicznej i Powłok Ochronnych. Od czasu wydzielenia i powołania Zakładu Powłok Ochronnych zakład funkcjonował od 1984 do 1993 roku. Następnie w 1993 roku powołano w Katedrze Chemii i Technologii Polimerów Pracownię Technologii Powłok Ochronnych, która w 1997 została przekształcona w Zakład. Od 2008 roku występuje w strukturze Wydziału jako samodzielny Zakład. Prowadzone przez pracowników Zakładu zajęcia dydaktyczne obejmują takie przedmioty, jak: technologia powłok metalowych, technologia powłok organicznych, metaloznawstwo i korozja metali, ochrona środowiska w technologii powłok ochronnych, ochrona obiektów przemysłowych, metody badania właściwości powłok. Ogółem specjalizację technologia powłok ochronnych ukończyło ok. 300. absolwentów. Z ważniejszych prac badawczych, które zostały wdrożone lub wykorzystane w zakładach przemysłowych, można wymienić: opracowanie technologii twardego chromowania narzędzi skrawających, technologię selektywnego nakładania lutowia Sn-Pb na ażury miedziane, technologię konserwacji narzędzi, trawienia i zabezpieczania międzyoperacyjnego. Początkowo tematyką badawczą Zakładu były badania korozyjności atmosfery, powłoki stopowe o specjalnym przeznaczeniu oraz dyspersje polimerów w środowiskach wodnym i organicznym, z uwzględnieniem nowoczesnych technik nanoszenia powłok. Obecnie głównymi kierunkami badań w Zakładzie są: badania utylizacji i wykorzystania ścieków oraz odpadów pogalwanicznych, a także odzysk metali powłokowych z detali i przedmiotów zużytych oraz wadliwie wykonanych; otrzymywanie farb wodorozcieńczalnych nie zawierających rozpuszczalników organicznych; badania aplikacyjne i ekspertyzy z zakresu korozji, powłok metalowych i organicznych, zabezpieczeń obiektów przemysłowych instalacji wytwórczych i aparatury oraz pojedynczych wyrobów.