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OPTIMIZING THE COMPOSITION OF UNPLASTICIZED POLYVINYL CHLORIDE PROFILES BY ADDING CHLORINATED POLYETHYLENE

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ABSTRACT

The synergistic effect of partial replacement of acrylic modifier with chlorinated polyethylene on the performance properties of extruded profiles made of rigid polyvinyl chloride was studied. Five dryblend formulations with different ratios of chlorinated polyethylene and acrylic modifier were prepared. Profiles with identical geometry (five-chamber frame) were extruded from them. Test specimens were prepared from the surface of the profiles. Tests were conducted and the physicomechanical properties of the tested samples were analysed. Based on this, the optimal content of chlorinated polyethylene in the dryblend composition was established. The impact and cold resistance, linear expansion, strength of the weld (thermally sealed corner), gloss and whiteness of the products were studied on the modified profiles. The aim of the present work is to improve the performance properties and reduce the cost of the final products by modifying the composition of the dryblend to produce profiles made of unplasticized polyvinyl chloride.

Keywords: unplasticized polyvinyl chloride, modification, properties, chlorinated polyethylene.

INTRODUCTION

Unplasticized polyvinyl chloride (PVC - U) is a widely used material in the construction industry, especially for window and door profiles. PVC - U profiles have established themselves as the preferred choice in modern construction due to their excellent thermal and acoustic insulation, energy efficiency, durability and good value for money. These products are available in a variety of colours and geometries [1]. One of the main advantages of the products is the possibility of recycling and returning them to the production process without any significant change in the properties of the recyclate. Despite its unique properties, PVC - U needs to be mixed with various additives to ensure optimal processing and operational properties [2, 3]. Its inherent brittleness is a major drawback that must be considered for the desired applications. This problem is exacerbated at low temperatures and in cold regions [4, 5]. Depending on the geographical location and the exposure of the installed products (windows and doors), the requirements for PVC-U profiles are different, which necessitates the modification of some of the characteristics. Any change in the composition of the dry mix leads to the optimization of the technological operating modes and careful monitoring and analysis of the influence of new additives.

As is known from the literature, acrylic modifiers are used to improve the impact resistance of PVC products for external applications (windows, siding, pipes and other durable applications). These modifiers, often with a “core-shell” structure, act by absorbing and dissipating the impact energy, improving the durability of the products. The elastic core absorbs the impact energy, while the shell layer improves the compatibility with the PVC matrix and facilitates dispersion [6 - 8]. The acrylic modifier (ACR) gives the products both excellent impact and weather resistance, as well as color durability [9, 10].

The combination of an acrylic modifier and chlorinated polyethylene (CPE) offers synergistic benefits for impact modification [6]. Chlorinated polyethylene is a modified form of polyethylene in which some hydrogen atoms have been replaced by chlorine atoms. This process improves the properties of the material, making it more resistant to heat, chemicals, and weathering. CPE is versatile and is used in applications such as cable insulation, PVC modification, and various rubber products. The degree of chlorination significantly affects the properties of CPE. Below 15 % chlorine, it behaves like a polymer. In the range of 25 - 48 % chlorine, it functions as an elastomer. Increasing the chlorine content increases oil resistance, air permeability, and flame resistance, while decreasing it improves cold resistance and flexural strength. These tenable properties make CPE a highly adaptable material for specific performance requirements. One of the most significant applications of CPE is as a modifier in the composition of polyvinyl chloride profiles. It increases impact strength. Approximately 74 % of global CPE consumption in 2017 was in this direction [11]. While ACRs are distinguished by improved impact resistance and transparency at room temperature, CPE provides excellent weather resistance, chemical resistance and, finally, a financially advantageous product [12]. Despite the widespread use of CPE as a modifier, the literature lacks data on specific studies of the influence of the combination of chlorinated polyethylene and an acrylic modifier on the performance properties of rigid polyvinyl chloride products.

EXPERIMENTAL

Materials and testing methods

In this work, an analysis of the physical and mechanical properties of PVC - U profiles made of dryblend with an acrylic modifier and those in which part of the modifier has been replaced with chlorinated polyethylene has been carried out.

Materials

The raw materials used are as follows:

Suspension polyvinyl chloride (PVC - S), Suspension Resin Grade: LS100H, K - value 67 and apparent density 0.599 g cm^{-3}, LG Chem LTD;

Chlorinated polyethylene WEIPREN 3135 - type CPE 135A, with chlorine content about 35 %, bulk density ≥ 0.50 g mL, provided by Weifang Yaxing Chemical Co., Ltd;

Acrylic modifier KIMSTAB EPRO 1000, apparent density 0.450 - 0.550 g cm^{-3}; manufacturer - KIMFLOR KIMYA SANAYI VE TICARET A. S.;

Stabilizer KIMSTAB EPRO 4000 on calcium-zinc (Ca - Zn) basis from KIMFLOR KIMYA SANAYI VE TICARET A.S.;

Calcium carbonate filler ($CaCO_3$) IOKALIT 5C EXTRA, manufactured by IONIAN KALK S.A., with particle size from 1.75 μm to 8.00 μm, whiteness according to certificate L = 98.59.

Pigment - titanium dioxide (TiO_2) - rutile, which is the tetragonal form of titanium dioxide, known for its stability. Provides excellent coverage (opacity), durability and gloss, with a high refractive index for gloss.

The production of test samples, modified with different ratios of CPE and ACR, was carried out by extrusion process. For this purpose, a twin-screw extruder, brand Cincinnati Milacron, equipped with a head for drawing five-chamber profiles was used.

Within the framework of the experimental work, five different formulations (R1 - R5) were formulated, in which the content of CPE and ACR was varied while maintaining the total amount of impact modifier. All other components are kept constant to ensure an objective comparison of mechanical properties. The table presents the basic formulation, in which only the acrylic modifier (R0) is present, and the five developed formulations with a gradual increase in the amount of chlorinated polyethylene, with formulation 5 completely replacing the acrylic modifier with chlorinated polyethylene. The dosages of the raw materials are presented in percentage (%). The formulations are presented in Table 1.

Profiles (five - chamber frame) for doors and windows were extruded under optimized technological operating conditions. Test specimens were made from the profiles, subject to testing and analysis, in accordance with the described standardized methods.

Test methods

1. EN ISO 179 - 2:2020 - Plastics - Determination of Charpy impact properties - Part 2: Instrumented impact test; specimens with dimensions: 80 mm (length) × 10 mm (width) × 4 mm (thickness), corresponding to Notched Charpy impact test specimens ISO 179 - 1/1eA. CEAST Impact test

Table 1: Formulations with different CPE and ACR ratios.

Raw materials	R0, at. %	R1, at. %	R2, at. %	R3, at. %	R4, at. %	R5, at. %
PVC	Const.	Const.	Const.	Const.	Const.	Const.
$CaCO_3$	Const.	Const.	Const.	Const.	Const.	Const.
TiO_2	Const.	Const.	Const.	Const.	Const.	Const.
Stabilizer	Const.	Const.	Const.	Const.	Const.	Const.
Acrylic modifier	6	4.9	4.3	3.3	2.9	0
Chlorinated polyethylene	0	1.1	1.7	2.7	3.1	6

device used - Italy with a 15 J hammer.

2. EN 477:2018 - Plastics - Poly(vinyl chloride) (PVC) based profiles - Determination of the resistance to impact of profiles by falling mass;
3. EN 514:2025 - Plastics - Poly(vinyl chloride) (PVC) based profiles - Determination of the strength of welded corners and T - joints;
4. EN 479:2018 - Plastics - Poly(vinyl chloride) (PVC) based profiles - Determination of heat reversion;
5. EN ISO 2813:2015 - Paints and varnishes - Determination of gloss value at 20^o, 60^o and 85^o;
6. EN ISO 7724 - 2 - Paints and varnishes - Colorimetry. Part 2: Colour measurement

The assessment of the visual qualities of PVC - U profiles is an important aspect of their overall technical characteristics, especially for products intended for facade and interior applications, where appearance is important to the consumer. In this study, two key indicators were measured - whiteness (parameter L), according to the requirements of the standards EN ISO 7724 - 1,2 and specular gloss (by 60^o), according to the requirements of the standards EN ISO 2813.

RESULTS AND DISCUSSION

This section presents and analyses the results of the physical and mechanical tests conducted on PVC - U profiles produced using five different formulations with varying ratios of chlorinated polyethylene and acrylic modifier, compared to the original formulation containing only ACR. The main objective of the analysis is to investigate the influence of chlorinated polyethylene on the performance properties of the profiles, with a focus on cold impact resistance.

Fig. 1 presents the results of the test to determine the thermal shrinkage of the profiles produced using the six formulations.

Fig. 1 presents the results of testing the different compositions according to the indicator "Heat shrinkage". As can be seen from the graph, the behaviour of the different compositions during testing is in accordance with the requirements of the standard. The 2 % line is the tolerance according to the product standard EN 12608 - 1:2016 + A1 [13]. The results of the tests conducted show a clear relationship between the ratio of modifiers and the degree of thermal shrinkage. At a higher ACR content, the shrinkage is less, which is probably due to the ability of this modifier to provide better homogeneity of the PVC matrix and a more uniform distribution of additives.

Fig. 2 presents the results of testing the products according to the indicator "Strength of welded corners".

As can be seen from the graph, the base recipe (recipe 0), containing only ACR, demonstrated significant strength of the welded joints (4.13 kN), which is higher than the tolerance specified in the product standard of 3.0 kN. The addition of small amounts of CPE (1.1 %) leads to a slight decrease in strength (3.95 kN). In recipe 2 (1.7 % CPE), a partial recovery of strength (4.05 kN) is observed, suggesting that in this range CPE begins to positively influence the distribution of internal stresses. With an increase in the CPE content to 2.7 and 3.1 % (recipes 3 and 4), the strength of the welded corners increases, reaching a maximum value of 4.43 kN in recipe 4. Excessive CPE content, as in recipe 5 (6.0 %), leads again to a decrease in strength (4.02 kN).

Fig. 3 presents the results of measuring the gloss and whiteness of the profiles depending on the CPE content (%).

The results show that the whiteness values (L

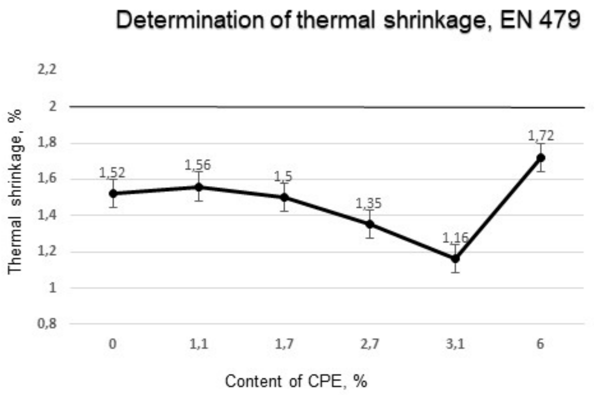

Fig. 1. Dependence of thermal shrinkage on the CPE content in the composition.

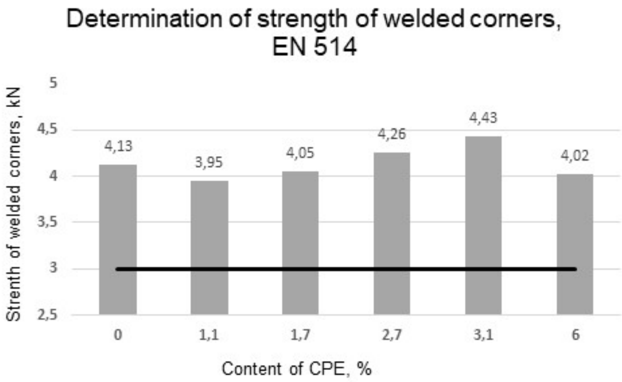

Fig. 2. Change in strength of welded corners depending on CPE content.

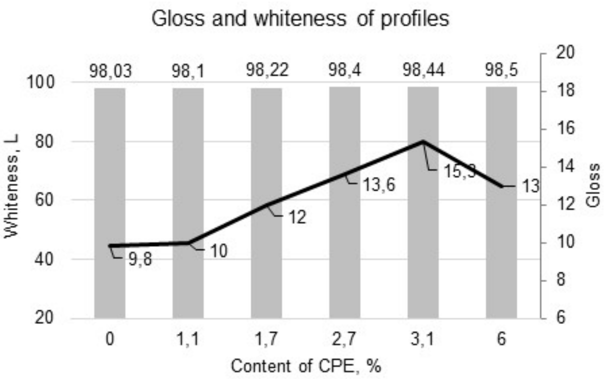

Fig. 3. Change of gloss and whiteness of profiles depending on the CPE content.

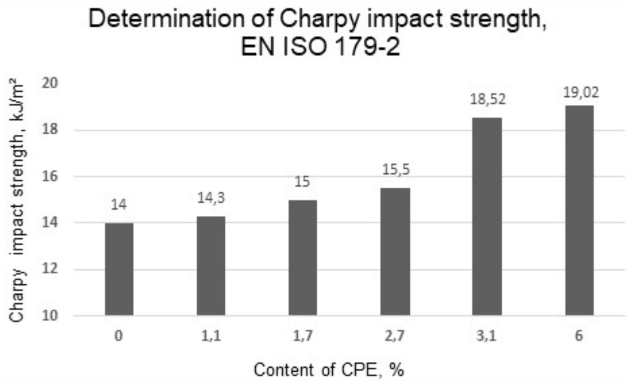

Fig. 4. Dependence of Charpy impact strength on the CPE content in the composition of the profiles.

value) remain relatively stable, varying within a narrow range from L = 98.03 to L = 98.5. The slight increase in the L parameter in recipes 4, 5 and 6 is a positive, but practically insignificant change. This is explained by the fact that the whiteness of PVC - U profiles is mainly determined by the content and dispersion of titanium dioxide (TiO_2) in the matrix, which acts as a pigment with a high reflection coefficient. The gloss of the surfaces reaches a maximum value at 3.1 % CPE, which is a 56 % improvement in the indicator compared to recipe 0.

The following Fig. 4 presents the results of testing the test specimens according to the Charpy impact strength indicator. This test has direct relevance in assessing the behavior of PVC - U profiles exposed to external influences - for example, impact, fall or extreme climatic influences.

The results in Fig. 4 clearly show that the addition of chlorinated polyethylene (CPE) has a significant impact on the impact toughness of PVC - U profiles. In the base recipe (0 % CPE), a strength of 14.00 kJ m^{-2} was achieved. In recipes 2 and 3, the strength increases smoothly, while in recipes 4 and 5 a significant increase in the value is observed, where the impact strength reaches 18.52 kJ m^{-2} - 19.02 kJ m^{-2}. This indicates a strong synergistic effect between ACR and CPE. The highest value was recorded when ACR was completely replaced by 6 % CPE. In recipe 5, an impact strength of 19.02 kJ m^{-2} was achieved, which highlights that CPE is extremely effective as an impact modifier. At the same time, however, the complete replacement of the acrylic modifier with CPE may lead to compromises with other properties - including thermal stability.

Fig. 5 presents the results of testing the experimental samples for the indicator “Impact resistance”.

As can be seen from the graph, with increasing CPE

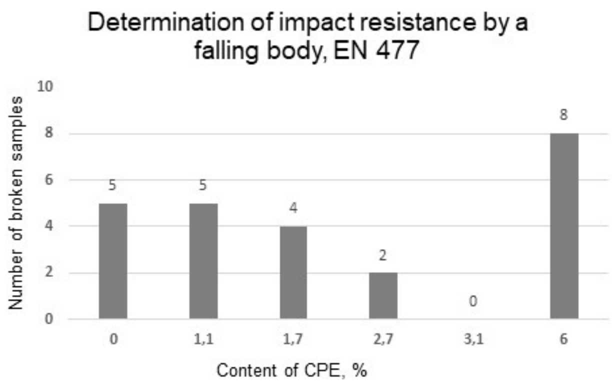

Fig. 5. Change in impact resistance by a falling body depending on the CPE content in the profiles.

content, the impact resistance of the profiles increases. In recipe 4 (3.1 % CPE), zero number of fractures is observed, which is evidence that at this concentration CPE provides optimal energy absorption capacity without compromising the structural integrity of the PVC profile. This could be explained by the fact that with this balance between ACR and CPE, the material retains its necessary stiffness and thermal stability (provided by ACR), but at the same time acquires sufficient elasticity and plastic deformability, thanks to CPE. The optimal combination between ACR and CPE is the only effective approach to achieve PVC - U profiles with high mechanical impact resistance, especially in low temperature conditions.

CONCLUSIONS

Using an industrial extruder, PVC - U blends with different ratios of chlorinated polyethylene and acrylic modifier were prepared. The influence of CPE on the physicomechanical properties of the resulting composites was studied.

It was found that the optimal thermal stability is achieved when adding up to 3.1 % CPE (recipe 4), where the lowest thermal shrinkage (1.16 %) is observed. The combination of ACR and CPE leads to an increase in the strength of the weld, with the highest result being recorded for recipe 4 kN - 4.43 kN. The addition of CPE has a limited influence on the whiteness of the profiles, with the L - value remaining stable within narrow limits (98.03 - 98.5) due to the constant concentration of TiO_2. More noticeable is the impact on gloss, which increases with increasing CPE content and reaches a maximum value of 15.3 GU in recipe 4 (3.1 % CPE). In the Charpy impact strength, a clear trend towards an increase in fracture energy with increasing CPE content was found. A maximum value of 19.02 kJ m^{-2} was reached in recipe 5. In the drop test, the data show that only recipe 4 (3.1 % CPE) did not break, confirming that this ratio of ACR and CPE offers the best balance between impact resistance, thermal stability and processability, making it an optimal choice for industrial applications.

Authors' contributions

The combination of 2.9 % ACR and 3.1 % CPE provides optimal thermal stability and cold impact resistance of unplasticized polyvinyl chloride profiles for doors and windows, without affecting the colour and gloss of the products. This combination is an optimal choice of compound for industrial applications.

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