INVESTIGATION OF BONDING CHARACTERISTICS OF POLYPROPYLENE-WOOD COMPOSITE

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Abstract:
Adhesive bonding technology is one of the most recent assembling techniques applied in industry and maintenance. Adhesives are versatile and offer a number of advantages over fastening techniques, however, there are number of limitations associated with their use.
One of the most difficult issues is bonding of low surface energy materials, such polyolefines (PE and PP), silicones, PTFE etc. In this investigation the attention has been paid to bonding of polypropylene-wood composite aiming to research the influence of wood filler on the bonding characteristics of polypropylene. The simple single lap bonded joints have been prepared. Two types of adherends - polypropylene and polypropylene-wood composite and two types of adhesives - a 2K toughened epoxy adhesive and a special low surface bonding 2K acrylic adhesive have been tested.

1. Introduction

The use of adhesive bonded joints in load-bearing structures is of great interest to the aerospace, automotive industry and to machine tools modules development as well [1]. Time and cost savings, high corrosion and fatigue resistance, crack retardance and good damping characteristics are the major advantages of these joints. Adhesives have a wide applicability and the adherend to which they are applied are also very diverse, both chemically and physically. Both of surface natures are important in adhesion and is often difficult to separate these two effects. The chemical nature influences the reactivity of the surface towards the adhesive. The surface energy and fundamental wetting characteristics also very affect on the strength and stability of adhesion [2].

Polypropylene and other polyolefins are materials which increasingly being used for automotive applications, due to their advantageous properties and ability to be recycled. The poor bondability owing to the low surface energy of such materials, has so far limited the wide spread use of these materials where joining is necessary.

In this situation is obviously that is reasonable to investigate the influencing factors on properties of adhesive bonded joints. It has special importance for application possibilities of polymer materials in new products, e.q. in automotive industry.

2. Problem statement

Although the use of fillers in plastics industry has been known for several decades, there is still a great interest for the development of composite materials with enhanced properties. Especially high tech products accelerate the research of advanced composites, which demand extensive knowledge of all the factors that determine ultimate properties of polymeric composite materials. Polypropylene is one of the most widely used commodity thermoplastics, especially in automotive, electric, packaging and consumer application. The reason for this can be found in its excellent properties, such as good processing, heat distortion temperature above 100°C, recycling ability and favourable price/performance ratio [3]. Despite its exquisite properties, the PP is very often modified with particulate fillers and other polymers. The most common fillers used in the PP are talc, calcium carbonate, glass beads, glass fibbers, mica, silica and wollastonite.

The properties of the composites depend upon the characteristics of components, composition, structure and interfacial interactions. The latter factor is affected by the size of the interface and the strength of the interaction. Both, the interface and strength of the interaction could be modified to improve the wettability and adhesion between the components by surface treatment with different modifiers such as stearic acid, silane and titanate coupling agents. Wetting of fillers and the adhesion between the filler and the matrix is governed by the principles of the theory of adhesion based on the surface energy properties of the filler and the matrix, respectively. For this reason the measurements of the surface properties of pure materials and composite materials could explain the applicability of composite materials when pure polymers are not acceptable for creating a reliable adhesive joint.

Generally, polymer materials in relation to other technical materials (metals and ceramics) have considerable lower values of free surface energies. This property of surface is of crucial importance for good adhesiveness of adhesive and achieving of reliable adhesive bonded joint. For successful bonding free surface energy of chosen adhesive type must be lower or even equal to free surface energy of adherend materials. At the same time most of the structural adhesives having a surface energy of 25-30 mJ/m^2. Unfortunately, polypropylene is one of the polymer types with the lowest surface energy which equals 29 mJ/m^2 (for comparison: aluminium has 840 mJ/m^2 and iron 2030 mJ/m^2), and is very difficult for adhesive bonding, whereby is limited in applications.

In recent time the special two-part acrylic-based adhesive that can bond many low surface energy plastics, including many grades of polypropylene, polyethylene, and TPO's without special surface preparation was developed. However, that adhesive is still in improving stage and is not reached their market age. Because of higher costs relating to standard structural adhesives (e.q. epoxy adhesives), those new adhesive is still not extended in great series parts bonding. Thereby, as consequences of mentioned difficulties is intruded a problem of adhesive bonding of low surface energy material researching. Wood is an attractive reinforcement due to its low density, low cost, renewable and biodegradable character, and reasonable processibility. Wood particles, such as chips, flakes, fibbers, flour and wood pulps, are used as reinforcement agents. These types of natural fibbers are able to satisfy both economical and ecological interests [5, 6, and 7].

Considering that polypropylene because of its properties is very unfavourable for adhesive bonding, the main goal of this paper is to make enhanced material with adding of wood particles. Following goal is to investigate the influence of wood flour on adhesion properties (load-bearing characteristics of adhesive bonded joints) of wood flour/polypropylene composites, and to compare mechanical properties of PP adhesive joints and wood-flour-filled PP adhesive joints.

3. Experimental investigation

The standard single lap specimens for evaluating the load bearing characteristics i.e. strength of adhesively bonded joint have been prepared accordingly Figure 1. Two types of adherends (materials to be bonded) have been considered; polypropylene and composite (polypropylene + 50 % wood by weight). All materials were injection moulded using ENGEL 330/60. Injection moulding parameters are presented in table1. Polypropylene properties of Hungary manufacturer are presented in table 2, and properties of wood flour of Germany manufacturer are presented in table 3. These materials are used for preparing of plate specimens for adhesive bonding.

Table 1. Injection moulding parameters

Processing parameter	Nozzle temp.	1st heater temp.	2nd heater temp.	3rd heater temp.	Injection rate	Injection pressure	Cooling temp.	Holding pressure	Holding time
Value	195ºC	195ºC	190ºC	190ºC	150 mm/s	1540 bar	20ºC	900 bar	1.5 s

The adherend plates are cleaned by an appropriate surface preparation method [4]. The objective of surface preparation is to remove loosely attached surface films such as oils, waxes, dusts, mill-scale, loose paints and all other surface contaminants in addition to enhancing mechanical adhesion. It is a standard surface preparation procedure. Dimensions of such prepared adherend plates were $a \times b \times s$=17×40×1,7 mm.

The 2K toughened epoxy adhesive DP190 and special 2K acrylic adhesive DP8010 are applied to the region to be overlapped. For acceptable mixing of A and B component of each adhesive, mixer nozzle with 20 elements was attached.

Table 2. Properties of PP (TIPPLEN grade K948, manufacturer TVK, Hungary)

Property	Unit	Value
MFR, 230°C/2.16kg	g/10 min	45
Flexural modulus of elasticity (drawn)	N/mm^2	1200
Tensile strength at yield	N/mm^2	27
Elongation at yield	%	5.5
Izod impact strength notched, at 23°C	kJ/m^2	8.5
Rockwell hardness	HRC	77
HDT	°C	100

Table 3. Properties of wood flour (Filtracel EFC 1000, manufacturer J. Rettenmaier & Sohne, Germany)

Raw material	technical raw cellulose
Color	light-brown
Structure	fibrous
Grain size, main share	70 µm - 150 µm
Bulk density	105 g/l - 140 g/l
Residue on ignition (850 °C, 4 h)	1%
pH-value	4.5 +/- 1

The thickness of the applied *DP8010* adhesive is maintain at 0,2 mm by micro spheres that the adhesive contains and at 0,4 mm by using of appropriate fixture device on both of prepared adherends. The standard structural epoxy adhesive *DP190* is also maintain at the same values of adhesive thickness as the special one. The overlap length has been set up on 17 mm. Such applied adhesive are allowed to cure to reach maximum strength (Figure 2).

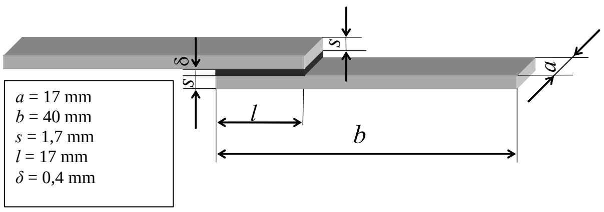


Figure 1. Single lap joint specimen

Figure 2. Bonding of composite specimen (curing of adhesive to reach maximum strength)

The all in this way prepared bonded joints have been stretched up to the break in the clamps of the tensile testing machine. All tests were conducted on *WPM, VEB Thuringer Industriewerk Rauenstein* 2,5 kN, Typ 2092 tensile testing machine. All tests are performed at room temperature.

4. Results and discussion

The adhesive shear strength (τ_a) has been calculated as a maximum shear stress achieved in an adhesive layer, based on recorded maximum tensile forces for each tested joints [5]:

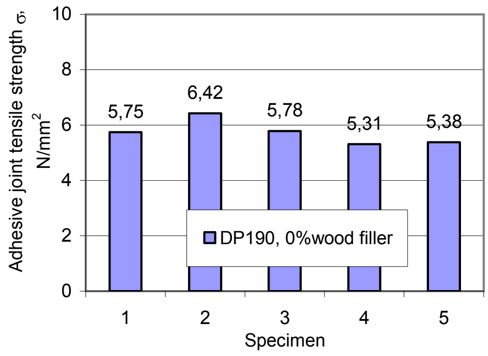
$$\tau_a = \frac{F_{max}}{l \cdot a} \tag{1}$$

and a joint tensile strength (σ_s) as a maximum tensile stress transferred crossover the joint:

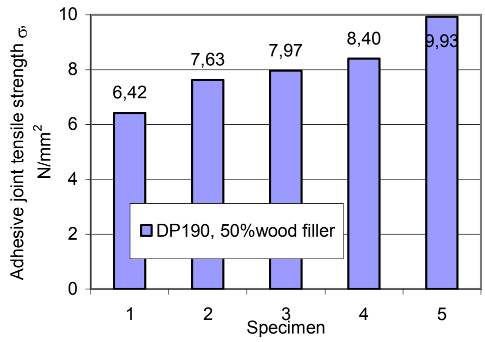
$$\sigma_s = \frac{F_{max}}{s \cdot a} \tag{2}$$

The values of joint tensile strengths are calculated by using the equation (2) and they shows load-bearing capacity of the bonded joint. Results of measured values are shown on figure 3 a) - 4 b); σ_{mean} presents the arithmetic mean values of adhesive joint tensile strength.

From the results presented on figures 3a and 3b (I and II), it is easy to note that achieved values of joint tensile strength at given overlap length has higher values in composite joints than in pure PP joints. Cases I present the results obtained after loading of adhesive joints which are made of PP, unlike cases II presents the results obtained after loading of adhesive joints which are made of polypropylene composite. With this approach there is only one results explanation adjust: greater values of load-bearing characteristics could only be caused by wood filler content in polypropylene. From the 3 a) figures the important effect could be noted: adhesive bonding of polypropylene composites resulted with the mean value of adhesive joint tensile strength of σ =8,07N/mm^2 and for the pure polypropylene joints that value was σ = 5,73 N/mm^2.

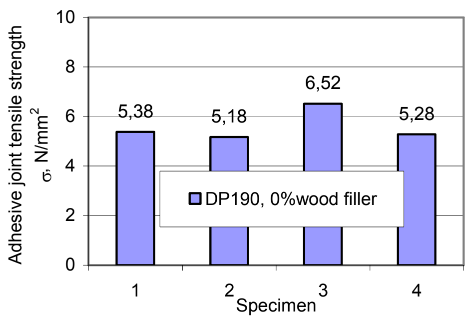


I (σ_{mean} = 5,73 N/mm^2)

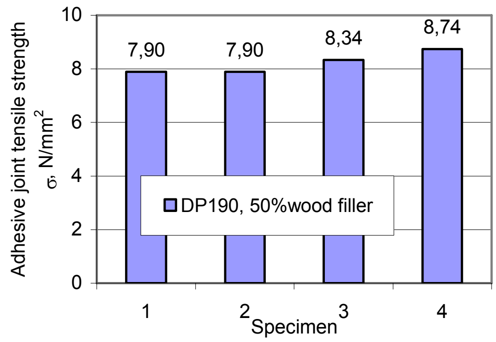


II (σ_{mean} = 8,07 N/mm^2)

a) adhesive thickness d_{adh} = 0,2 mm



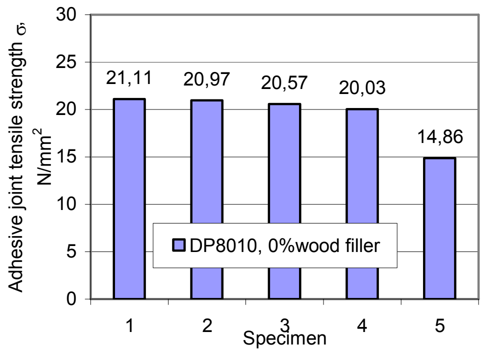
I (σ_{mean} = 5,59 N/mm^2)



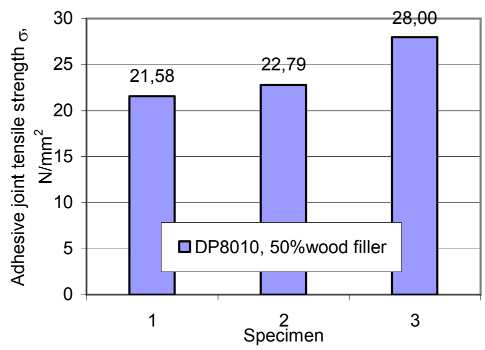
II (σ_{mean} = 8,22 N/mm^2)

b) adhesive thickness d_{adh} = 0,4 mm

Figure 3. Experimental results of specimens tensile testing: adhesive joints are made with 2K toughened epoxy adhesive

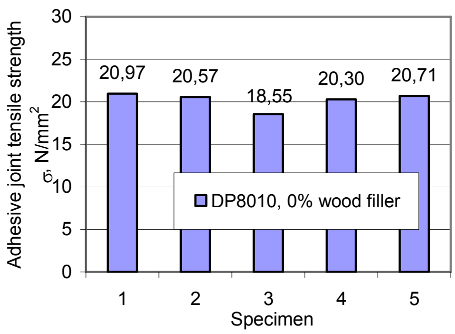


I (σ_{mean} = 19,51 N/mm^2)

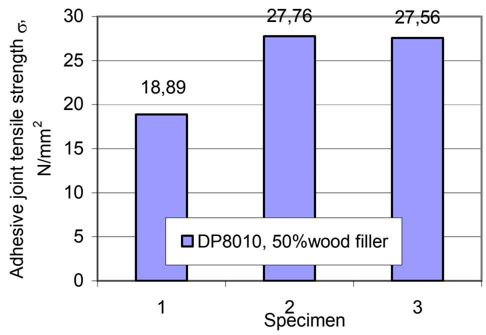


II (σ_{mean} = 24,12 N/mm^2)

a) adhesive thickness d_{adh} = 0,2 mm



I (σ_{mean} = 20,22 N/mm^2)



II (σ_{mean} = 24,74 N/mm^2)

b) adhesive thickness d_{adh} = 0,4 mm

Figure 4. Experimental results of specimens tensile testing: adhesive joints are made with special 2K acrylic-based adhesive DP8010

It means that composite joints in this case might transmit for 41% greater values of loading. For the thicker layer of adhesive (figure 3b); d_{adh} = 0,4 mm) the similarly conclusion could be noted: with the 50% content of wood filler in polypropylene for the 47% greater values of loading could be reached.
Bonding with the special adhesive for low surface energy plastics caused quite different results. From the results presented on figures 4 a) and b) can be seen that composite joints might transmit greater values of loading. In case of thinner adhesive layer (0,2 mm) that increasing equals 23,62%, and for thicker adhesive layer (0,4 mm) increasing equals 22,35%. Such special adhesive already cause higher adhesion forces, so that filler content in polypropylene doesn't came into expression in increasing of adhesive forces. Thereby, better results (in increasing of adhesive forces with adding of wood filler) might be achieved with the standard structural adhesive (over 40%), than with the special adhesive (about 23%).
Failure mode by fracture was also noted quite different in PP/adhesive and composite/adhesive joints cases. Testing of PP/adhesive joints shows that failure is the mostly in adherend (figure 5a). In composite/adhesive joints testing mixed mode of failure exist (figure 5b).

a) adherend: PP; adhesive: DP8010

b) adherend: PP composite; adhesive: DP8010

Figure 5. Failures of adhesive joints

5. Conclusion

In this investigation the polypropylene-wood composites were testing, aiming to research the influence of wood filler on the bonding characteristics of polypropylene. The study of wood filler influence confirmed better bonding properties of such enhanced materials for both of adhesive thickness used in specimen for testing. By defined geometry of single lap joints, even for the 47% greater values of loading could be reached by adding of wood filler in polypropylene composites.
This preliminary investigation confirmed the thesis that bonding of low energy materials is possible and gives better results by using of filler in material. Further investigation will follow already provided testing which is presented in this paper. Study will be focused on adhesive joints failure mode. Authors are planning to add different wood filler content in polypropylene matrix.
Mechanical features of adherend materials will be tested, so numerical analyses could be provided.

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