EVALUATION OF THE ADHESION STRENGTH OF DOUBLE-SIDED COATED SELF-ADHESIVE TAPES AND THERMAL ADHESIVE

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ABSTRACT

The work presents an experimental evaluation of the bonding strength of materials commonly used in printing industry, using double-sided adhesive tape and thermal adhesives. The study revealed changes in adhesive strength when bonding various types and structures of paper and cardboard surfaces, as well as laminated glossy and matte surfaces. The experimental study aims to identify surfaces that exhibit optimal adhesive tape adhesion. Moreover, there are also surfaces that should not be used with double-sided tape, but instead should be glued with thermal adhesives. In addition, the study examines the effect of different separation rates on the bond strength of these materials. The results provide valuable information about the adhesive properties of materials in the printing industry, providing useful information for professionals to optimize printing processes and ensure the production of high-quality and durable printed products. The data presented in this article can assist in selecting appropriate adhesives for a variety of printing applications, which will achieve consistent and reliable results and can greatly affect their quality and durability.

Keywords: adhesion strength, double-sided self-adhesive tapes, thermal adhesive, mechanisms of adhesion.

INTRODUCTION

In the production of certain printed products, e.g. packaging, boxes for gifts or cosmetics, lamination of prints takes place after printing to protect the surface of the prints, make the product more durable, protect it from scratches during transportation or placing on shelves, etc. Later, when forming a box or other package, the edges are glued with hot glue or joined using double-sided adhesive tape. The problem that occurs is related to the strength of the bond. When joining with double-sided adhesive tape, the tape bounces off the laminate. Similar problems arise when attaching two sheets of decorative paper - the double-sided adhesive tape also peels off after a while. According to the customer's request, it is often necessary to glue different materials, and it is not always clear which joining method is better to choose - using hot glue or double-sided adhesive tape - in order to have sufficient strength of the package, bag or other product. It is relevant to carry out a study that allows to objectively assess the strength of the adhesive when using adhesive tape and glue. Based on the results of the study, recommendations can be made to improve work productivity and reduce the probability of defective products.

This study evaluated four commonly used materials that are bonded with "Folsen" double-sided adhesive tape and compared the adhesion of the same materials using hot glues that are dispensed by the "Lamina system" machine.

Pressure sensitive adhesive tape was investigated by Barrios [1]. He has mentioned, that the possibility of using ready-available PSA tapes can therefore simplify the demonstration of prototypes or proof-ofconcept devices. Free-radical bulk-photopolymerization process as a method of obtaining thermally curable structural self-adhesive tapes and effect of used type I photoinitiators were introduced by Gziut et al. [2]. They presented a new and environmentally friendly method of obtaining thermally curable structural self-adhesive tapes. Influence of a nanoclay on the thermo-mechanical properties of silicone pressure-sensitive adhesives was investigated by Antosik and Mozelewska [3]. They mentioned, that from an economic point of view, a great advantage is the possibility of obtaining materials with maximum utility values using small amounts of filler. Influence of illite and its amine modifications on the self-adhesive properties of silicone pressure-sensitive adhesives were shown by Antosik et al. [4]. Their new self-adhesive materials developed based on the given tests show a higher thermal resistance than the unmodified tapes available on the market. Preparation and characterization of acrylic pressure-sensitive adhesives crosslinked with UV radiation-influence of monomer composition on adhesive properties was given by Mozelewska et al. [5]. They mentioned, that the incorporation of an unsaturated photoinitiator monomer into the copolymer chain results in high self-adhesive parameters.

Basics of research

Double-sided adhesive tapes need glue to stick. In the production of adhesive tapes, so-called pressure-sensitive adhesives are used. Pressure-sensitive adhesives are permanent adhesives that adhere to a surface only when pressure is applied. Chemical reactions are not required to create the adhesive force. Adhesives that meet two requirements are suitable for bonding two materials: on the one hand, the adhesive must ensure that the adhesive tape remains attached to the surface as long and strongly as necessary (adhesion); on the other hand, the internal strength of the adhesive itself must meet the intended purpose (cohesion) [6]. It is generally accepted that single-sided adhesive tape must meet the basic properties (adhesion > 10 N/25 mm; retention > 8 N/25 mm; cohesion > 72 hours) in order to be applied according to specific areas, e.g. heavy industry [7].

Double-sided tape can be either thin (such as paper-based) or thick (such as foam-based), coated with rubber, acrylic, or a modified version of these sometimes with differential properties. Double-sided tapes with thick bonding systems are usually better able to bond to unusual, non-uniform, or highly patterned and textured surfaces. Thick bonding systems usually involve a foam carrier layer and may vary significantly in strength. Thin bonding systems are, as the name suggests, much thinner - sometimes so thin that they consist of nothing but pure adhesive on a silicone liner [8].

The adhesive tape is perfect for industrial use, demonstrating its advantages. It effectively levels uneven surfaces and significantly speeds up the process, as it does not require drying time, unlike liquid glue. There are no toxic fumes emitted during its use. Additionally, the tape ensures cleanliness since there's no residue to wipe off after the gluing process [6].

Different types of glue are used for bonding different materials. Depending on which products and materials are glued, universal or specialized glues are chosen. Adhesives that contain solvents are generally avoided. One such solvent-free adhesive is thermoplastic adhesive or hot glue. Recently, they have become very popular in the printing industry. A mixture of polypropylene and various resins is usually used in the production of adhesives. In other words, it is a plastic that remains solid at room temperature. It liquefies at heating, but unlike other types of glue, it hardens incredibly quickly. It is waterproof and non-toxic. The glue is tacky when hot, but hardens within a minute or even a few seconds. Higher temperature hot melt adhesives spread easily on the surface but are less durable, lower temperature hot melt adhesives are more difficult to use but have particularly good properties and are strong [9].

The glue penetrates into the pores of the material of the object to be glued and hardens there, or the fibers of the surface of the substrate penetrate into the glue layer and, after the latter hardens, become fixed in the glue layer and mechanical adhesion occurs on this principle. Therefore, mechanical forces hold the polymer layer to the adhesive surface (Fig. 1) [10].

From the physics point of view, the adhesive properties depend on the interaction of three forces: tack; adhesion (adhesion to the surface); cohesion (bonding of glue particles). The adhesive's cohesive force is based on the molecular interaction of its components - polymers. Polymers form long mobile chains of molecules. After reaching a certain length, these chains intertwine with each other, which increases the cohesion of the adhesive

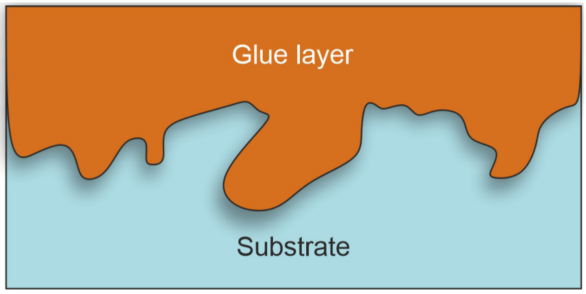


Fig. 1. The penetration of the glue layer into the pores.

- the internal attraction of the particles.

Pressure sensitive adhesives work through three main forces: tack, cohesion, and adhesion. Tack refers to the initial contact between the adhesive and the surface, determining the speed at which the bond is formed. Adhesion refers to the physical joining between two substances, notably evident in dissimilar substances. In adhesive tape, adhesion characterizes the bond between the adhesive and the surface it adheres to. The last force in a pressure-sensitive adhesive is cohesion, representing the internal bond strength within the adhesive itself. High cohesion signifies a robust, durable, and stable adhesion, crucial for situations requiring strength against tearing or when bearing substantial weight. Strong molecular bonding ensures the adhesive tape remains intact, maintaining stability and preventing it from tearing or losing grip under heavy loads [6].

Two steps are required to evaluate bonding: bonding the materials and breaking the resulting bonding. Three main methods of surface separation can be distinguished: adhesive, cohesive and mixed (Fig. 2). Adhesive release occurs when the adhesive layer separates from the substrate. If the bonded surfaces have separated through the adhesive layer or by the degradation of the substrate, it is cohesive separation. When the bonded materials separate after the breakdown of both the substrate and the adhesive layer, a mixed separation occurs [10].

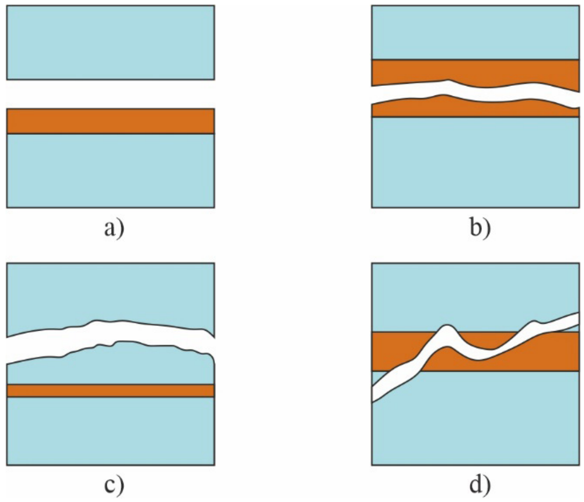


Fig. 2. Methods of separation of glued surfaces: a) Adhesive failure; b) Cohesive failure (through the adhesive layer); c) Cohesive failure (through the substrate); d) Mixed failure.

EXPERIMENTAL

Problem formulation

In a general sense, it is still not known which type of connection will give a better adhesion effect, whether double-sided adhesive tape or glue. Both the one and the other type of connection are widely used, but the clear difference and advantages (adhesion force) have not been studied enough. This work aims to try to reveal those differences. It should also be mentioned that this study is focused on cases where production circulations are small, in this case the dilemma remains which type of connection to use, small production is still relevant. It should be noted that thermal adhesives are used for large runs. In any case, reaching a solution, preparatory work takes time, so this study has practical value.

Materials and Methods

The following substrates were used for the study: paper “Rives tradition” 170 gsm; cardboard “Kreative Karton Sapphire” 350 gsm; glossy laminate “Deprosa” and matte laminate “Deprosa”. Double-sided adhesive tape “Folsen” 6 mm (Fig. 3(d)) and hot glue “GluMelt EC 2800” were used for bonding the samples.

The aim of the experimental research is to determine which surfaces are better bonded by Folsen double-sided adhesive tape and which are better bonded by hot glue.

Adhesion strength was determined experimentally using the computer-controlled tension-compression test system, Mecmesin *MultiTest* 2.5-I (Mecmesin Limited, UK), load sensor measurement error: 0.1%. The testing machine (Fig. 3(a) was controlled using the *Emperor Force* software (Mecmesin Ltd., UK).

Tests were performed at different stretching

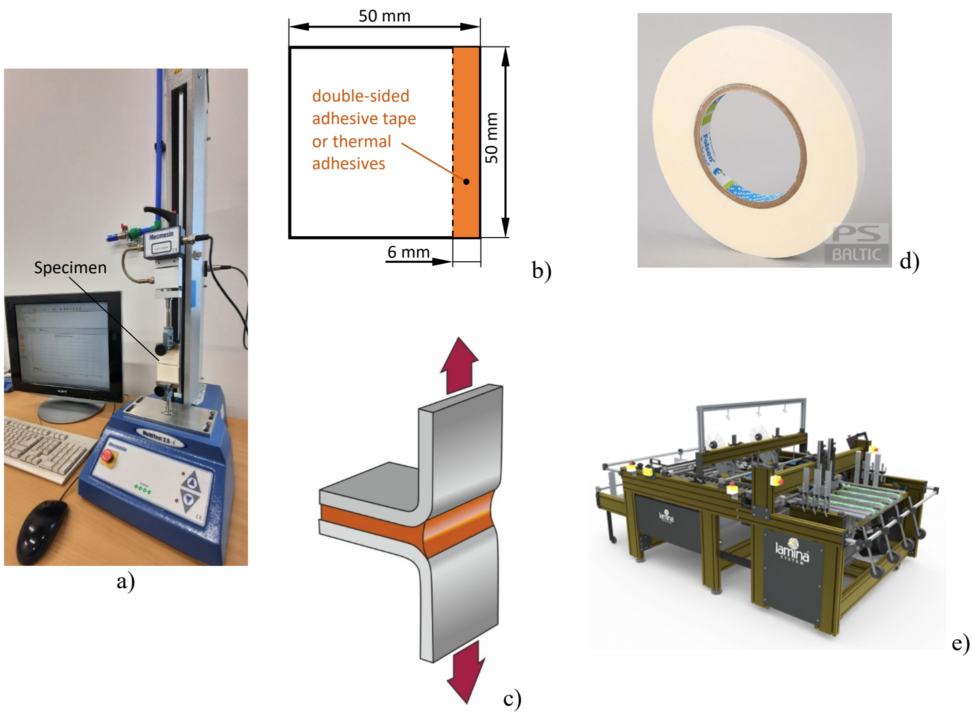


Fig. 3. Equipment and sample preparation for the research: a) Single-column force tester MultiTest 2.5-I with fixed specimen; b) Dimensions of the specimen; c) The loading of the specimens during the test; d) Double-sided adhesive tape "Folsen" (PS-Baltic); e) "Lamina System" semi-automatic glue machine (Lamina System).

speeds: 1 mm min^{-1}, 100 mm min^{-1} and 500 mm min^{-1}. The application of load at different speeds is related to the practical potential load of bonded objects, e.g. single-use glued products stand or hang and have little load change, while a product such as a bag has a fast load change when carried by handles.

The specimens are prepared by cutting the appropriate size from the test material and fixing it in the testing machine. Samples were cut out of the intended materials for research - 50x50 mm. Two specimens of the same size were glued together with 6 mm wide double-sided adhesive tapes, the tape was glued right next to the edge (Fig. 3(b)). The samples of the same size were also glued together using thermal glue with the "Lamina system" gluing machine (Fig. 3(e), the width of the glue strip was also 6 mm.

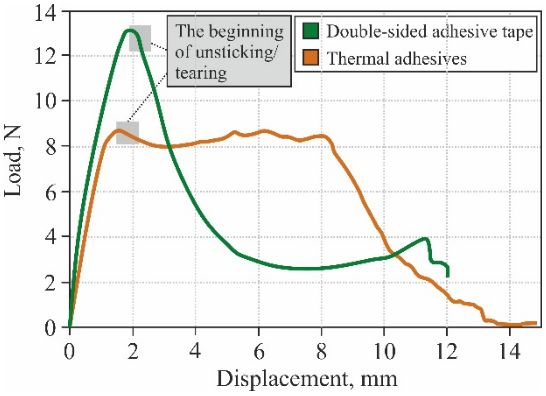
Fig. 3(c) shows the load of the specimens during the test. On Fig. 3(e) a semi-automatic gluing machine "Lamina System" is shown.

RESULTS AND DISCUSSION

Adhesion strength evaluation at a separation rate of 1 mm min^{-1}

Fig. 4 shows the test results of samples made from Rives tradition 170 gsm paper. The maximum load at which debonding starts with double-sided tape is 13.1 N, while the bonded joint with hot glue begins to separate at 8.6 N. The results showed that the strength of the adhesive is weaker than that of double-sided tape. However, although the adhesive bond started to break down at a lower load, but such bond was more stable, the debonding was gradual. This should be taken into account depending on the product being manufactured.

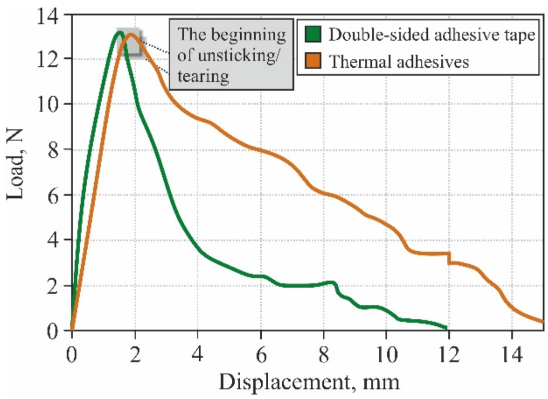
Fig. 5 shows the test results of samples made from cardboard "Kreative Karton Sapphire" 350 gsm. According to the obtained results, the maximum load of both the adhesive and the double-sided adhesive tape using this substrate is similar - 13.7 N. Separation rate



a)

b)

Fig. 4. Test results of samples made from paper "Rives tradition" 170 gsm. a) Unsticking/tearing results at 1 mm min^{-1} tretching speed; b) Specimen at the end of the test.



a)

b)

Fig. 5. Test results of samples made from cardboard "Kreative Karton Sapphire" 350 gsm. a) Unsticking/tearing results at 1 mm min^{-1} stretching speed; b) The specimen during the test.

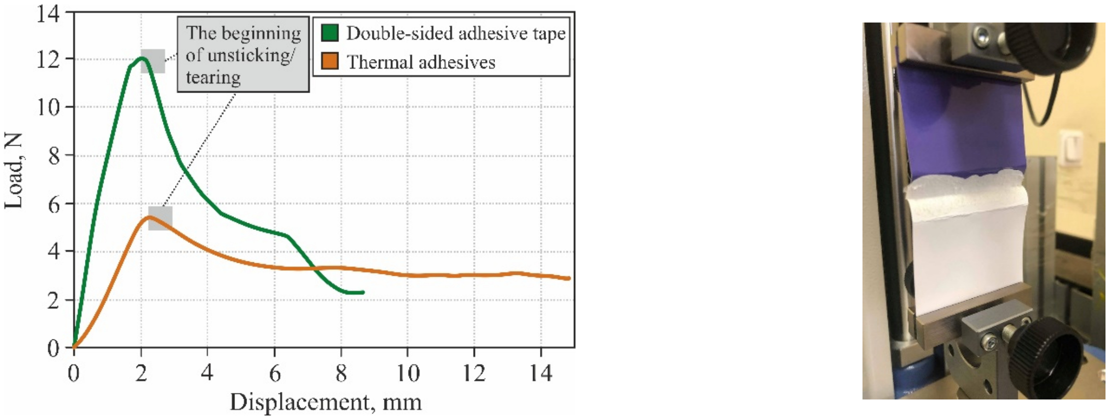
of 1 mm min^{-1} requires significantly less load on the specimens than using higher speeds. These differences can be seen in the following graphs at 100 mm min^{-1} and 500 mm min^{-1}

Fig. 6 shows the test results of the samples made from bonded gloss laminates. The laminated side is bonded to the non-laminated side. The maximum load at which the sample begins tearing when bonded with glue is only 5.3 N, while the bonded joint with double-sided tape begins to separate at 11.9 N. In the connection with glue, cohesive separation is more pronounced. The adhesive had sufficient adhesion to the substrate as the material was ripped out (Fig. 6(b)). The fibres of the paper stuck to the glue and separated from the paper. It can be concluded that its glue is strong enough, but for such glued laminate it is more appropriate to use double-sided adhesive tape.

Fig. 7 shows the test results of the samples made from bonded "Deprosa" matte laminate. The results show a stronger bond with hot glue. The maximum load at which the sample begins tearing when bonded with thermal adhesives is 18.3 N, while the bonded joint with double-sided tape begins to separate at 16.5 N.

Adhesion strength evaluation at a separation rate of 100 mm min^{-1}

Fig. 8 shows the test results of samples made from Rives tradition 170 gsm paper. At this separation rate, the maximum load at which debonding of the double-sided tape starts is 32 N, which is approximately 2.5



a) b)

Fig. 6. Test results of samples made from glossy laminate “Deprosa”: a) Unsticking/tearing results at 1 mm min^{-1} stretching speed: b) The specimen made from glossy laminate bonded with hot glue, during the test.

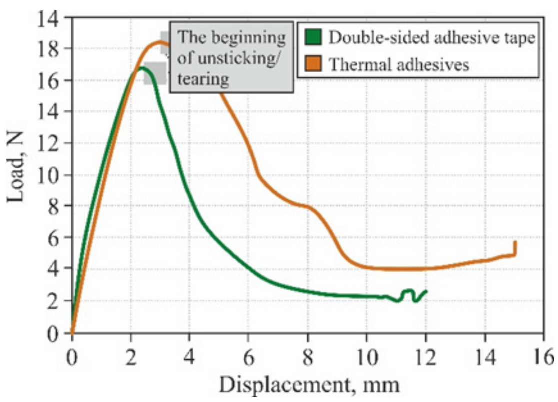


Fig. 7. Unsticking/tearing results of samples made from “Deprosa” matte laminate at 1 mm min^{-1} stretch rate.

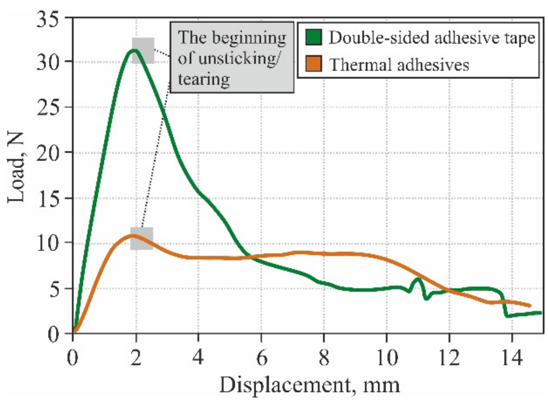


Fig. 8. Unsticking/tearing results of samples made from paper “Rives tradition” 170 gsm at 100 mm min^{-1} stretch rate.

times higher than for separation at 1 mm min^{-1}. The bonded joint with hot glue begins to separate at 11 N, i.e. at approximately 3 times lower load. Paper “Rives tradition” has a rough surface, so the glue does not fill the material gaps well and the materials quickly tear from each other. Therefore, when using this material, especially with a larger grammage, it is better to choose a double-sided adhesive tape.

Fig. 9 shows the test results of samples made from cardboard “Kreative Karton Sapphire” 350 gsm. The result shows that a stronger bond is obtained using double-sided tape.

At a separation rate of 100 mm min^{-1}, the bond strength of the specimens made from Deprosa glossy laminate (Fig. 10) and Deprosa matte laminate (Fig. 11) is higher when double-sided tape is used compared to thermal adhesion. The maximum load at which debonding starts of matte laminate with double-sided tape is 43.7 N. This is a very good result compared to the other tested materials.

Adhesion strength evaluation at a separation rate of 500 mm min^{-1}

Figs. 12 - 15 show the results of tests evaluating the bonding strength of the same substrates at a separation rate of 500 mm min^{-1}. In all cases, a stronger bond was found using double-sided adhesive tape. The load at which the separation begins with double-sided adhesive

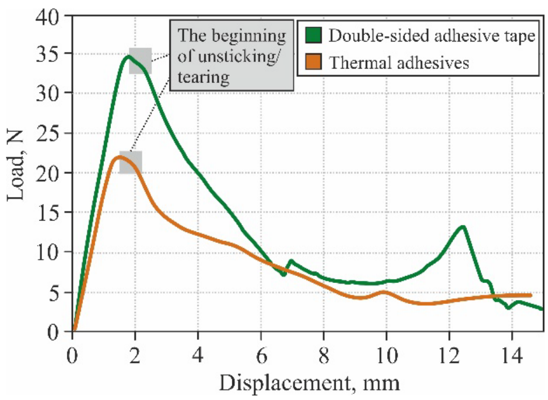


Fig. 9. Unsticking/tearing results of samples made from cardboard "Kreative Karton Sapphire" 350 gsm at 100 mm min^{-1} stretch rate.

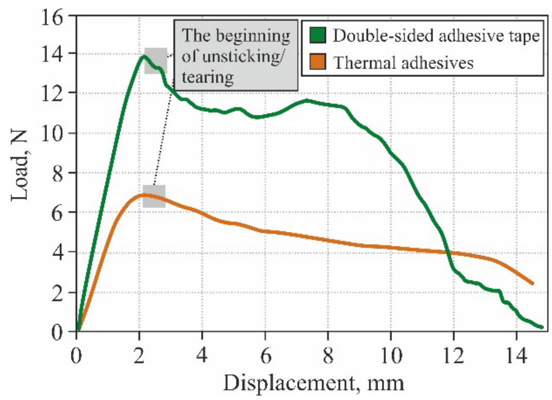


Fig. 10. Unsticking/tearing results of samples made from glossy laminate "Deprosa" at 100 mm min^{-1} stretch rate.

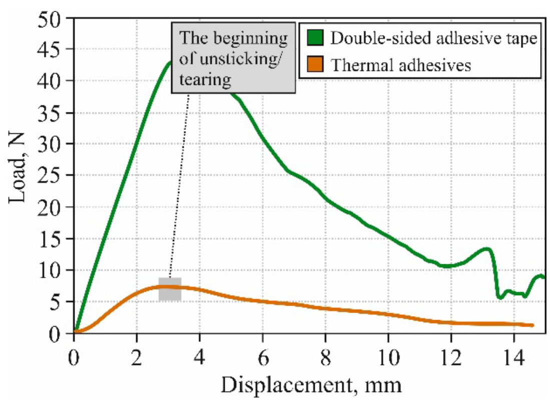


Fig. 11. Unsticking/tearing results of samples made from "Deprosa" matte laminate at 100 mm min^{-1} stretch rate.

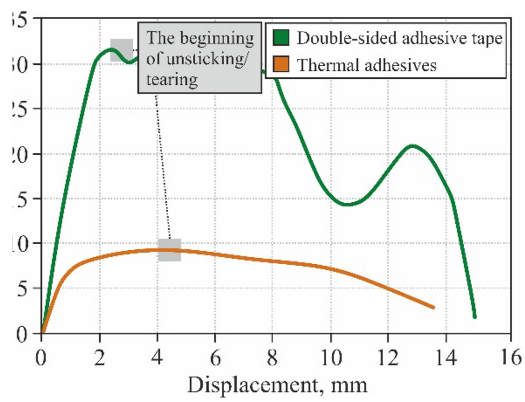


Fig. 12. Unsticking/tearing results of samples made from paper "Rives tradition" 170 gsm at 500 mm min^{-1} stretch rate.

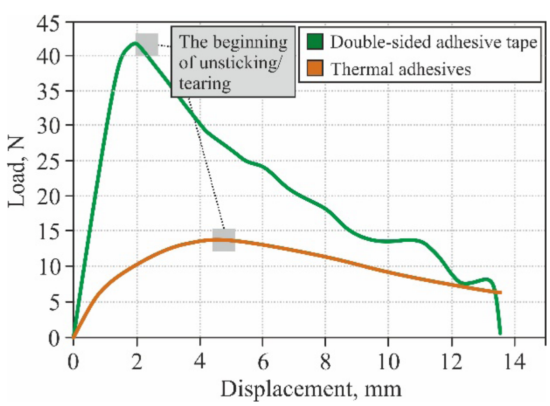


Fig. 13. Unsticking/tearing results of samples made from cardboard "Kreative Karton Sapphire" 350 gsm at 500 mm min^{-1} stretch rate.

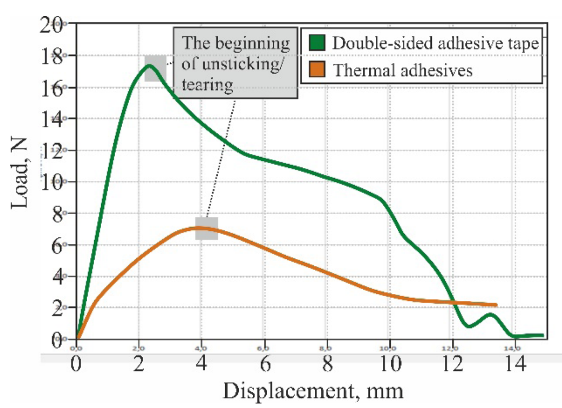


Fig. 14. Unsticking/tearing results of samples made from glossy laminate "Deprosa" at 500 mm min^{-1} stretch rate.

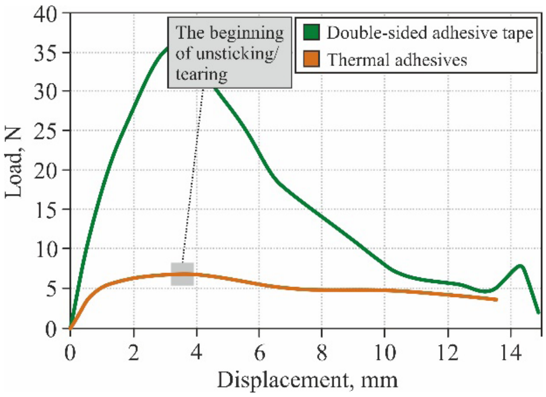


Fig. 15. Unsticking/tearing results of samples made from “Deprosa” matte laminate at 500 mm min^{-1} stretch rate.

tape is in all cases about 3 times higher compared to hot glue, and even more than 5 times with matte laminate.

Comparison of adhesion strength of different substrates

Below (Figs. 16 - 18) are the results of various substrates bonded with double-sided adhesive tape and thermal adhesive tear test results at the maximum load value corresponding to the onset of tearing/debonding. The graphs show the ratios of maximum loads and it is possible to draw conclusions in which case of use, which gluing method should be chosen, ensuring sufficient adhesion and not risking defective production.

At a lowest separation rate, i.e. 1 mm min^{-1} the highest maximum load at which debonding starts is determined of matte laminate. Both double-sided adhesive tape and hot glue have the highest load values for this substrate, but hot glue shows better bond strength (Fig. 16).

At 100 mm min^{-1} separate rate the highest maximum load at which debonding starts is determined of matte laminate but only if double-sided adhesive tape is applied (Fig. 17). The lowest maximum load at which debonding starts is determined of the specimens made from Deprosa glossy laminate. The glossy surface of the substrates makes it difficult to achieve good adhesion, especially with the hot glues used in the study.

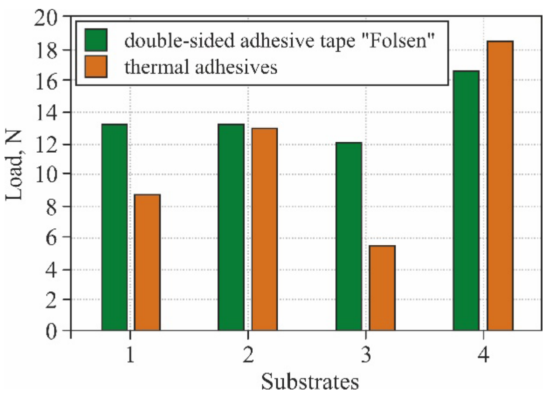


Fig. 16. Maximum load at which unsticking/tearing begins when the stretching speed is 1 mm min^{-1} (1 - paper “Rives traditional”, 2 - cardboard “Kreative Karton”, 3 - glossy laminate, 4 - matte laminate).

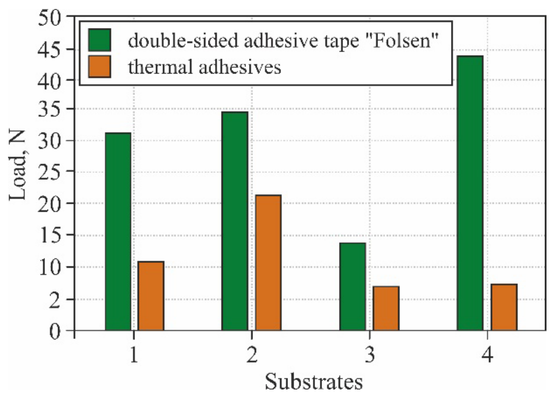


Fig. 17. Maximum load at which unsticking/tearing begins when the stretching speed is 100 mm min^{-1} (1 - paper “Rives traditional”, 2 - cardboard “Kreative Karton”, 3 - glossy laminate, 4 - matte laminate).

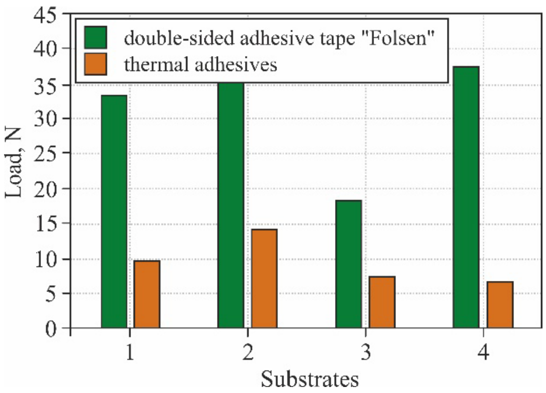


Fig. 18. Maximum load at which unsticking/tearing begins when the stretching speed is 500 mm min^{-1} (1 - paper “Rives traditional”, 2 - cardboard “Kreative Karton”, 3 - glossy laminate, 4 - matte laminate).

Similar results of bonding strength were determined at a separation rate of 500 mm min^{-1} (Fig. 18). A stronger bond was found with all substrates using double-sided adhesive tape.

CONCLUSIONS

- During physical experiment it is observed that gluing with hot glue using an automatic gluing machine is more efficient than gluing double-sided adhesive tape by hand, but the bonding strength with glue is lower. For all materials tested, the adhesive strength is higher with double-sided adhesive tape than with hot glue.
- When evaluating bond strength, the separation speed has a noticeable effect on the determined maximum withstand load - in almost all cases, as the speed of detachment increased, the value of the withstand load until debonding/rupture increased. The highest values until debonding were obtained when testing the samples at the speed - 500 mm min^{-1}. At a tensile speed of 500 mm min^{-1}, the bond strength using double-sided adhesive tape was found to be about 3 times higher than that of hot glue.
- In order to improve the work performance and glue products with an automatic gluing machine, it is necessary to change the glue to one with better adhesion parameters.
- It could be also mentioned, that experiment confirm known effect, that glossy laminate has poorer adhesion than matte laminate due to its slippery surface.

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