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COMPREHENSIVE ANALYSIS OF METAL–POLYMER SANDWICH COMPOSITE MANUFACTURING

Introduction

Metal-polymer sandwich composites can be competitive with monometallic sheet materials in household, automotive, aerospace industries. It can provide mechanical properties that comparable to monometallic sheets but with lower weight benefit. Therefore, it can help to fulfil such economic as well as ecological objectives as weight reduction of construction parts, materials and fuel economy in automotive and aerospace engineering. Nowadays, most of construction parts in those industries are made of metals and alloys, although polymeric composites are being gradually implemented.

Furthermore, polymeric materials can provide such desirable physical properties in specific appliances as low thermal conductivity, low electrical conductivity or vibration and acoustic damping. Nevertheless, they have no sufficient rigidity and strength to be used independently. Hence, in order to use them in case of strength properties demands polymeric materials should be combined with reinforcing parts. Metal-polymer sandwich is the particular occasion of such combination

The formulation of the purpose of article

This literature research is dedicated to the complex analysis of metal-polymer sandwich composite structures manufacturing by means of rolling.

Effect of pressure on mechanical properties of amorphous and semi crystalline polymers, influence of such rolling factors as thickness reduction, surface roughness, rolling temperature, rolling speed, existing problems of providing bonding strength, current disadvantages of the failure mode assessment also mechanisms of adhesion bonding between metallic and polymeric materials was analyzed in this paper in accordance with the latest publications. It was emphasized a necessity of studying the negative influence of polymer degradation on bonding strength. In order to solve this problem the utilizing of local welding was proposed.

Specification of metal-polymer sandwich composites

Such type of composite material consists of two metal skin layers and at least one polymeric layer between them as it is depicted at figure 1. Layers of sandwich can be bonded to each other either by means of adhesive (which way is more common) or without using an adhesive, so-called “direct adhesion” [1, 2].

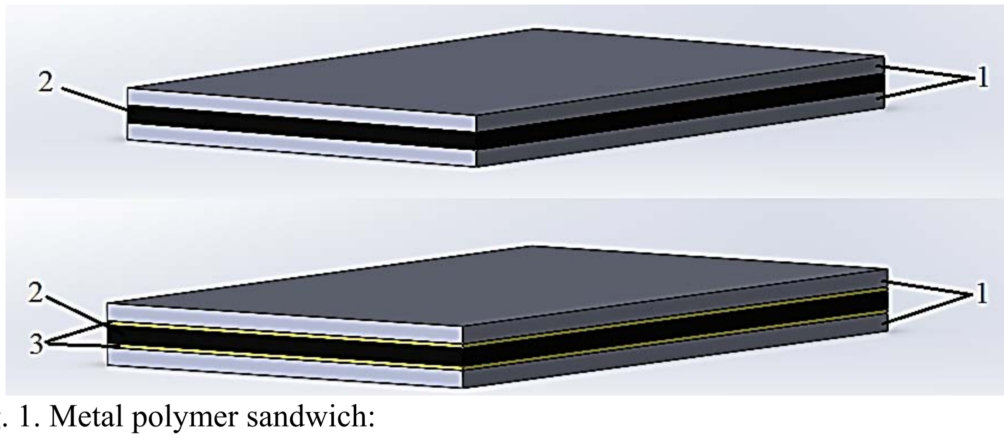

Fig. 1. Metal polymer sandwich:
1 – Metal (skin) layers; 2 – polymeric core; 3 – adhesive agent

Numerous types of metal-polymer sandwich composites were produced. Several of them consist of metals outer layers and fiber reinforced polymeric core such as: aramid fiber aluminum laminate “ARALL” [3–5], “GLARE”, with fiber glass reinforced plastic as a core [4] “CARALL”, that made of carbon reinforced plastic core and aluminum outer layers [4, 6], “HTCL”, consisting of titanium alloy, carbon fibers and thermoplastic resign was designed for application in aerospace industries.

Nowadays companies provide metal-polymer sandwich composite materials for wall panel systems such as: ALUCOBOND [7], ALPOLIC [8] or REINOBOND [9] that consist of two aluminum skin layers bonded to the polyethylene core.

Utilizing of metal-polymer sandwich materials instead of conventional metal sheets in transport industry for body parts can be a good decision from the point of view of fuel economy and ecology pollution decreasing.

In the paper that was written in 2005 [10] was discussed application possibilities of Hylite which is made of two 0.2 mm AA 5182 aluminum strips and polypropylene core 0.8mm. Hylite was utilized for pre-validation manufacturing of 500 bonnets basis of VW Lupo. Besides that, Hylite was used for top panels in Audi A2. In another paper [11] studying of formability of AA5182-polypropylene sandwich was carried out for manufacturing of bonnet also its stiffness was measured and compared with bonnet made of steel and accordingly to paper bonnet has satisfying stiffness although it 65 % lighter than corresponding bonnet made of steel and 30 % lighter than bonnet made of aluminum sheet only. Nevertheless, it has lower formability than steel sheet for automotive industry.

According to [10] it was tested for application in railway carriages, can be utilized for manufacturing of skin plates of doors, and inside roof cladding also it is used in shipbuilding for manufacturing interior cladding panels and skin parts of honeycomb floor. Eastman Kodak Company introduced X-Ray cassette with Hylite panels replacing the conventional aluminum panels.

Metal-polymer sandwich materials can provide other benefits, such as acoustic and vibration damping. In the work that was written in 2001 [12] materials for vibration damping were reviewed. According to the article polymeric materials have better vibration damping properties than steel and aluminum alloys, what makes MPM materials good for decreasing of in-cabin sound in cars or applying for manufacturing of washing machine panels.

Another one benefit of polymeric inner layer is decreasing of thermal conductivity comparable to a conventional monometallic material. Therefore utilizing them as a material for a refrigerator walls can be promising.

Manufacturing of metal-polymer sandwich composites

Metal-polymer sandwich composites that based on fiber reinforced plastic core are manufactured via combination of curing fiber strengthened polymeric core and either pressing or stamping [5], what limits length and width of the products and composites based on conventional polymeric core usually are produced by rolling process. On the one hand rolling allows providing continuous process and makes manufacturing more productive, on the other hand pressing lets achieve bonding of sandwich materials that contains non-plastic reinforcing inclusions such as carbon or glass fibers.

Influence of rolling polymer on the mechanical properties.

Polymers have differ deformation behavior relatively to metals and alloys and it must considered during material selection for metal-polymer sandwich composition

Amorphous polymeric materials tend to sufficient shape recovery at glass transition temperature after pressing and its degree depends on temperature and deformation ratio. In the paper [13] rolling of such amorphous thermoplastic polymers as: polycarbonate, polyphenylene oxide, polysulfone, ABS, polyvinyl chloride at room temperature was investigated. In specific cases recovery of rolled polymeric sheets thickness after annealing could reach 40–60 %, also hardness decreasing up to 20 % was after thickness reduction to 25 % was observed, then after surpassing this reduction, hardness starts to increase and attains its initial value. Impact strength of rolled polymers increased until reduction of 10 % was gained, then gradually decreased up to 30 %, and drops after following reduction raising. Hardening after rolling very little depends on the temperature of the process [14, 15]. Depending on thickness reduction tensile strength can increase more than 100 % and uniaxial rolling leads to anisotropy of mechanical properties, i.e. they are increase in rolling direction and do not change in transverse direction, biaxial rolling increases mechanical properties in both directions but in twice less amount than in uniaxial direction [13, 14].

It was shown that rolling of amorphous polymers at room temperature leads to density rising [13], while rolling of crystalline polyoximethylene has shown reduction of crystalline percentage and density at room temperature, percentage of crystallinity rises in direct ratio with temperature increasing and density started to increase as temperature raised up to 127 ºC for this material [14].

Adhesion and bonding strength

In the paper [16] three types of an adhesion between metal-polymer structures was distinguished: mechanical adhesion that depends on the surface roughness; chemical adhesion that based on chemical reactions between layers that is being bonded; physical adhesion – interaction forces (attraction and repulsive forces).

Mechanical adhesion is based on penetration of polymer into roughness valleys or into relatively porous oxidic layers of metal [17, 18]; Physical adhesion is provided by means of dipole, van der Waals, valence forces. Chemical adhesion – by means of covalent forces and chemisorption [16, 19]. In addition, chemical adhesion can be based on hydrogen bonds as result of interaction between oxidized surfaces [19].

To gain a metal-polymer sandwich composite material that can be utilized in different engineering purposes strong bonding connection between layers of composites is demanded. Bonding strength can be assessed via peel test or shear test.

Thus, in works [1, 2] parameters of direct (without adhesive) roll bonding aluminum- polyurethane sandwich composite was investigated. It was shown that increasing of thickness reduction up to 75 % of the sandwich increases bonding but squeezing of polymer is possible in case of such high reduction. Surface roughness increases bonding strength but also complicates polymer penetration into the roughness valleys and metal projections are stress concentrators so, after certain value of roughness, bonding strength can be weakened. Thickness reduction below 40 % was insufficient to provide bonding.

It is well known [20–22] that higher temperature of roll bonding process decreases threshold deformation that is required in order to provide welding between layers of metal, in case of bonding a polymer material to a metal sheet temperature of bonding is limited by the polymer softening point, researches in work [2] had chosen optimal temperature of rolling 200 ºC for the sandwich with polyurethane core.

In the work [20] where roll bonding of two strips made of Cuprum was investigated, it was observed that increasing of rolling speed causes decreasing of bonding time and as result the bonding strength, but on the other hand higher velocity of deformation increases the temperature at the bonding area, what has positive influence of bonding [2]. However, impact of contact time reduction after following increasing of rolling speed overcomes heating influence on the bonding and it weakens.

In addition, several methods of component surface treatment can be applied in order to improve adhesion strength mechanically, either chemically or physically:

- For mechanical bonding: grinding [1, 2, 23], brushing or sand blasting [23], what allows controling surface

- For chemical bonding: Using adhesive promoters, electrochemical etching, acidic or basic anodisation [20, 23].

- For physical bonding: Corona treatment, plasma treatment [20, 23] or Flame treatment [20.]

In general, utilizing adhesive agent allows achieving higher bonding strength between metallic and polymeric layers than direct adhesion of solid polymer to metal skin. For instance, in research [1], where bonding of Aluminum skin layers and polyurethane core, the highest average peel strength was gained 1.41 N/mm, and in the research [24] peel strength of sandwiches made of 0.2/0.5/0.2 and 0.3/1.0/0.3 steel/polyethylene-polypropylene was in range from 5.5 N/mm to more than 7 N/mm.

Bonding assessment

Usually researchers, who investigates adhesion strength of metal-polymer sandwich composites, distinguish two types of failure mode during the bonding strength estimating – cohesive failure and adhesive [1, 2]. Cohesive failure mod is characterized by destruction of polymeric or adhesive middle layer so the volume of polymeric layers remains on both surfaces of outer layer (figure 1a) and adhesive failure is characterized by delamination with absence of polymeric core or adhesive on one of the outer layers as it is shown on the figure 1b.

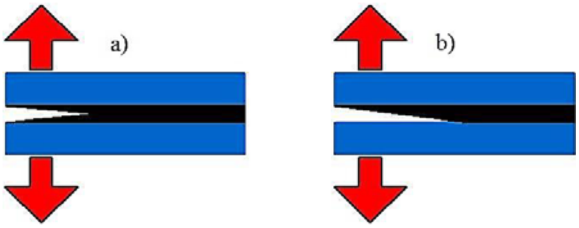

Fig. 2. Failure mod during peeling test:
a – cohesive failure; b – adhesive failure

Due to higher bonding strength of adhesion than cohesion, cohesive failure mod is necessary in order to provide firm connection between layers. However, according to the works [24, 25] a mixed mode must be distinguished. Example of adhesion failure mod is depicted on figure 3 [25].

Mixed failure mode occurs due to interface degradation and represents remaining much smaller volumes of adhesive on one metal layer than on the other and has attributes of both cohesive and adhesive failure. Despite that, such type of failure mod can be mistakenly qualified as a cohesion failure because of existence of small traces of adhesive on metal layer [25], what leads to erroneous conclusions of failure mod investigation and can cause harm due to overestimated bonding strength in a region of mixed failure mode.

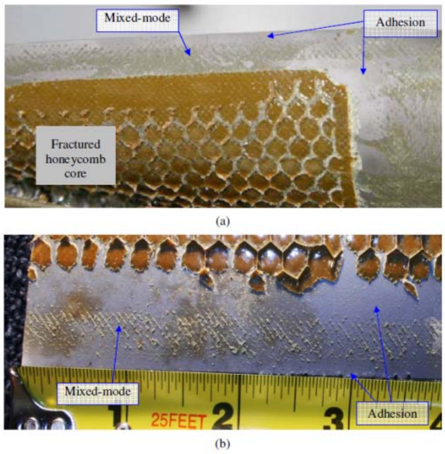

Fig. 3. Adhesion failure mod:
a – disbond surface from a main rotor blade; b – disbond surface from a main rotor blade of a crashed aircraft [25]

Formability of metal polymer sandwich materials

It was observed that in general, formability of metal-polymer sandwich sheets is less than that of conventional sheet metal also bonding strength and its quality across the whole bonding area plays an important role during forming processes. Sandwich sheets are prone to delamination due to forming or bending, what also leads to wrinkling, formability of a sandwich is restricted by polymeric core [23].

In order to solve the forming problem researchers [23,27–29] proposed the idea of utilizing reinforcing inlays. The reinforcement has the form of circle solid or meshed [27–29] steel inlay that substitutes a part of polymeric core. Such type of inlays can be used in case when fastening or welding (only for solid) connection between sheets is required, also the formability of metal-polymer sandwiches with local reinforcements was investigated by the authors. It was shown that inlay reduces thinning and stiffens of the sample during the deep drawing, an inlay should be bigger that the punch [28], cracking failure during deep drawing starts from outer metal layer and propagates through the polymeric core [1, 29] polymeric core tends to delaying the crack propagation [1].

SUMMARY

Comprehensive analysis of literature sources dedicated to bonding of metal-polymer sandwich composites via rolling, effect of bonding on sandwich formability and effect of rolling on mechanical properties of polymers was carried out in this paper.

According to the literature sources, combination of metal and polymeric materials into a multilayered composite is a prospective one due to such favorable properties as high acoustic and vibration damping, low thermal and electrical conductivity.

- Manufacturing metal-polymer sandwich composites by means of roll bonding is more favorable due to possibility to set up the endless process, however, for those sandwich composites, which are based on fiber reinforced plastic, rolling isn't an option due to non-plastic inclusions.
- Amorphous polymeric materials are prone to recovery after plastic deformation at glass transition temperature and rolling at several degrees below that stabilizes them. It was not found any information referred to influence this effect on bonding strength with metal.
- Unidirectional rolling causes anisotropy of mechanical properties and biaxial rolling halves and equalizes yield strength in rolling directions. Also rolling of crystalline polymers leads to decreasing of crystallization volume and density.
- Increasing of thickness reduction and surface roughness raises bond strength but their excessive values can cause polymer squeezing out of polymer and poor penetration polymer into roughness valleys.
- Rising temperature decreases threshold deformation of bonding, however, for metal-polymer sandwich temperature is restricted by polymer softening point.
- Increasing of rolling speed creates two competing factors: contact time between layers is decreased what weakens the bonding but also increasing of speed raises temperature and the deformation zone what has positive influence on the bonding.
- Utilizing adhesive allows obtaining higher bonding strength.
- It is important to take mixed failure mode into account while adhesion bonding is being assessed in order to avoid overestimating adhesion quality. Also the lack of research referred to studying of different conditions on polymer degradation and adhesive bonding has been found during the literature research.
- Delamination of metal-polymer sandwich composite causes wrinkling during sheet forming processes. It was proposed to solve this problem by utilizing local metal inlays in the region that if being formed e.g. deep drawn of bended, however, such inlays would affect benefits of using polymeric layer e.g. damping, heat conductivity etc. and this has not been studied yet.
- As it was mentioned polymeric core tend to degradation and bodning strength decreases with time, from this point it can be perspectively to research the increasing of bonding strength by means of local welding of metallic layers small local inserts that orderly distributed across the composite.

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