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ANALYSIS OF THE TECHNOLOGICAL EFFORT OF CONNECTING BRIDGE DESTRUCTION DURING PACKAGING MANUFACTURING WITH FLAT DIE-CUTTING PRESSES

Loizyk V.V.
PhD student.
ORCID: 0009-0007-0832-4199
Bryndas A.M.
PhD student.
ORCID: 0009-0004-4575-6749
Ternytskyi S.V.
c.t.s., associate professor
ORCID: 0000-0002-3814-9762
Lviv Polytechnic National University, Ukraine, Lviv, Bandera Street 12, 79013

Abstract. *The article considers a pressing problem in the packaging industry related to optimising post-press processing of paperboard blanks, particularly waste removal and cut-outs separation. An analysis of scientific and technical literature was conducted, which revealed a shortage of fundamental research devoted directly to the mechanics of the destruction of connecting bridges, which are used for the transportation of die-cut blanks through the equipment units. The article aims to study the fundamental aspects of the destruction process of technological bridges in paperboard blanks. The main direction of the work is to establish quantitative dependencies between the destruction force of these connecting elements and the technological parameters and mechanical characteristics of paperboard. The results will create a scientific basis for improving technological processes and equipment in paperboard packaging manufacturing.*

Keywords*: paperboard packaging, die-cutting, connecting bridges, technological destruction effort, internal waste.*

Introduction.

In today's dynamic packaging industry, cellulose-based materials such as paper and paperboard are leading. They account for a significant share, approximately one-third, of the total volume of packaging solutions used worldwide. This demand is primarily due to their favourable physical and mechanical characteristics.

The production of paperboard packaging is a multi-stage technological cycle that includes several technological operations [1]. One of this chain's fundamental and critically essential stages is the die-cutting operation. The execution of the die-cutting operation generates a technological problem associated with ensuring the kinematic stability of the paperboard sheet during its further transportation through the equipment sections. This phenomenon is because there is a partial violation of the structural integrity of the source sheet, which can lead to unwanted displacement of individual

elements of the web or the entire workpiece relative to the trajectory of movement. To level this effect and ensure controlled passage of the material through the production line, the technology forms miniature connecting elements during the die-cutting process - the so-called connecting bridges [2].

Statement of the problem.

Modern die-cutting machines (Fig. 1) are complex, technical, multifunctional and highly productive systems that integrate several autonomous technological units in their design.

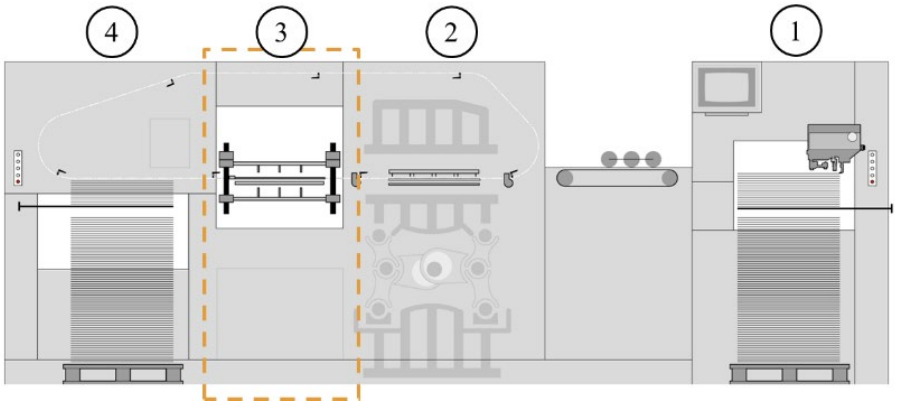

Fig. 1. Scheme of the die-cutting in flat presses

Source: developed by the authors

The paperboard packaging cut-outs manufacturing process uses such equipment as feeding paperboard sheets (position 1) to the working area. Next, in the specialised die-cutting section (position 2), direct contact of the die-cutting form with the paperboard sheet occurs, resulting in the outer and inner contours of the cut-outs. After that, the paperboard sheet, which already contains the cut-outs, technological bleeds of the format sheet and internal waste, is transported to the next section - the waste removal section (position 3). Specialised tools mechanically remove the “extra” elements at this stage, namely the edges and internal trimmings. The final stage of the technological process is the delivery of finished, cleaned waste cut-outs and, if necessary, separated packaging cut-outs (position 4) from the machine for further operations or storage.

Implementing operations for breaking out (removing) technological waste is carried out by controlled destruction of the bridges mentioned above. For this purpose, die-cutting machines use specialised tools and mechanisms to ensure high productivity and efficiency of waste removal and cut-outs separation.

The study [3] shows the analysis of the general loads arising in the die-cutting press and the deformation characteristics of the most flexible elements of its drive mechanism during operating modes. The work [4] is devoted to developing theoretical foundations for calculating the process of cutting out external curved contours in paperboard cut-outs using the scissor-cutting method. The work [5] proposes a methodology and appropriate tools for studying technological efforts directly in the die-cutting operation. The proposed approach allows data on the technologically necessary die-cutting efforts as a function of the movement of the working tool to be obtained. In the scientific work [6], the authors studied the technological efforts of breaking waste from a die-cut paperboard sheet. This study made it possible to obtain data on the effort required to destroy the connecting bridges. The authors consider the obtained experimental and analytical results as a foundation for further research into dynamic loads arising in the components of automatic stamping machines. Considering the analysis of scientific publications, it becomes evident that the primary focus of research is to study the processes of forming webs of paperboard consumer packaging, whether by die-cutting.

Presentation of the primary research material.

Paperboard has a pronounced anisotropy of physical and mechanical properties, which significantly complicates accurately predicting its behaviour and deformation-strength characteristics during mechanical processing, particularly during die-cutting and cut-outs removal operations. This anisotropy results from the predominant orientation of cellulose fibres in the MD during their production. The complexity of paperboard behaviour is due to its unique structure and physical and mechanical characteristics, which combine the attributes of polymeric materials and composite structures. One determining parameter that limits the technological modes and efficiency of post-press processing operations of paperboard blanks, particularly waste

removal, is the force required to destroy the technological connecting bridges. The destruction process of these bridges is characterised by elastic-plastic deflection of the paperboard blank in the zone of localisation of the bridge, which precedes the immediate beginning of its destruction (rupture), as illustrated in Fig. 1). Understanding this stage of deformation is essential for optimising the geometry of the tool and the kinematics of the process of removing scraps.

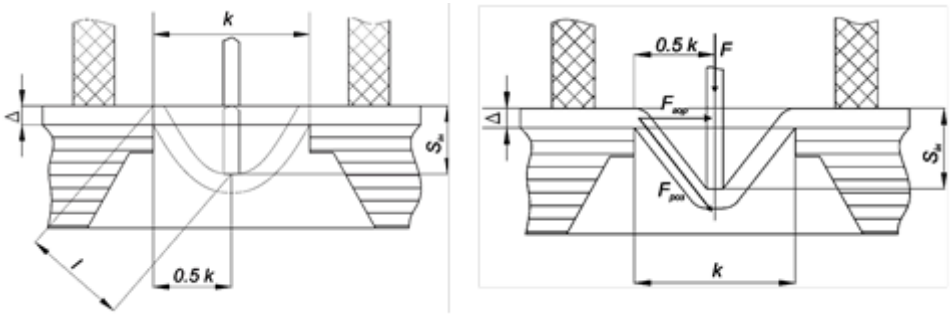

Fig. 2. Interaction between the tool and the paperboard sheet

Source: developed by the authors

The elongation of the paperboard blank can be determined:

$$\Delta l = \sqrt{0,25 \cdot k^2 + S_{in}^2} - 0,5 \cdot k \,, \tag{1}$$

where k – the width of the gap in the form for cut-out removal; S_{in} – the value of the special tool's vertical movement that is enough to destroy the structure of the paperboard blank.

In turn, the value of the deformation will be:

$$\varepsilon = \frac{\sqrt{0,25 \cdot k^2 + S_{in}^2}}{0,5 \cdot k} - 1 \,. \tag{2}$$

To ensure the destruction of the bridge, it is necessary to evaluate the value of the vertical movement of the special tool:

$$S_{in} = \frac{F_{\max} \cdot k^3}{4 \cdot E \cdot a \cdot \Delta^3} = \frac{\left[\sigma_{роз}\right] \cdot a \cdot \Delta \cdot k^3}{4 \cdot E \cdot a \cdot \Delta^3} = \frac{\left[\sigma_{роз}\right] \cdot k^3}{4 \cdot E \cdot a \cdot \Delta^2} \,, \tag{3}$$

where F_{max} – the maximum force value required to break the structure of a paperboard blank; Δ – paperboard thickness; E – elasticity modulus; a – connection bridge width.

The special tool will stretch the material in the first stage of the bridge destruction. To evaluate the value of the force required to ensure such deformation:

$$F_{роз} = F_1 \cdot \cos\alpha, \quad (4)$$

where $\alpha = \arctan\left(\frac{0,5 \cdot k}{S_{ін}}\right)$.

The value of the paperboard rupture stress:

$$\sigma_{роз} = E \cdot \frac{\Delta l}{0,5 \cdot k}$$

Knowing the value of the maximum tool movement, you can determine the force required to break the bridge::

$$F = E \cdot a \cdot \delta_к \left(\frac{\sqrt{0,25 \cdot k^2 + S_{ін}}}{0,5 \cdot k}\right) \cdot \cos\left(\arctan\left(\frac{0,5 \cdot k}{S_{ін}}\right)\right)$$

For a deeper understanding of the fracture mechanics of paperboard materials, the primary task is to quantify the force required to break interfiber bonds. Achieving this task requires comprehensive experimental studies to identify and formalise the influence of the microstructural parameters of individual cellulose fibres and the macrostructural characteristics of the sheet material as a whole on the complex of its deformation-strength properties.

Summary and conclusion.

Paperboard packaging manufacture inextricably depends on die-cutting and waste removal operations, where technological bridges that require controlled destruction play a key role. Paperboard, a complex anisotropic material, requires an in-depth study of its behaviour during local destruction. Therefore, the primary task is to quantify the force of destruction of bridges through comprehensive experimental studies. The scientific data obtained during the research and the developed models have significant practical value. They allow for targeted optimisation of technological parameters of production processes at all stages of paperboard production. The ultimate goal is to ensure stable packaging manufacture with specified, predicted operational characteristics, allowing stable production of high-quality packaging and increasing the productivity of paperboard packaging manufacture.

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Анотація. *У статті розглядається актуальна проблема пакувальної галузі, пов'язана з оптимізацією процесів післядрукарської обробки картонних заготовок, зокрема, операцій видалення обрізків та розділення розгорток. Проведено аналіз науково-технічної літератури, який виявив дефіцит фундаментальних досліджень, присвячених безпосередньо механіці руйнування цих перемичок. Метою статті є дослідження фундаментальних аспектів процесу руйнування технологічних перемичок у картоні. Основний напрямок роботи полягає у встановленні кількісних залежностей між зусиллям руйнування цих з'єднувальних елементів та визначальними конструктивно-технологічними параметрами і структурно-механічними характеристиками картону. Очікується, що отримані результати створять наукову основу для вдосконалення технологічних процесів та обладнання у виробництві картонного паковання.*

Ключові слова: *картонне паковання, штанцювання, з'єднувальні перемички, технологічне зусилля руйнування, внутрішні обрізки*