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Beata GRYNKIEWICZ-BYLINA*, **Bożena RAKWIC**
KOMAG Institute of Mining Technology, Gliwice, Poland
* Corresponding author: bbylina@komag.eu

TESTING THE STRUCTURAL STRENGTH OF BABY CARRIERS

Key words: safe use of products, baby carriers, testing the structure strength.

Abstract: Baby carriers used for carrying babies and toddlers belong to the articles which can cause injuries, including serious ones resulting from a child's fall from a height. This fact has been confirmed by the US Consumer Product Safety Commission – CPSC as well as by notification of the European Rapid Alert System for dangerous non-food products – RAPEX.
The strength of a baby carrier structure, including dynamic strength, associated with a vertical movement of a carrier loaded with a child's mass, attached to the torso of moving carer, is a parameter determining its safe use.
The results of the research project on testing the strength of soft carriers, using the author's testing procedure, are presented. Baby carriers commercialized on the Polish market within the years 2012–2018 were the testing objects. The tests enabled an identification of types of damages to the carriers for children that may occur during their use as well as to point at those design parameters which should be changed.

Badania wytrzymałości konstrukcji nosideł miękkich dla dzieci

Słowa kluczowe: bezpieczeństwo użytkowania wyrobów, nosidła, badania wytrzymałości konstrukcji.

Streszczenie: Nosidła stosowane do transportu niemowląt i małych dzieci należą do artykułów, których użytkowanie może prowadzić do urazów, w tym poważnych, spowodowanych upadkiem dziecka z wysokości. Fakt ten potwierdzają dane amerykańskiej agencji rządowej *Consumer Product Safety Commission* – CPSC oraz notyfikacje europejskiego *Rapid Alert System for dangerous non-food products* – RAPEX. Parametrem decydującym o bezpieczeństwie użytkowania nosideł jest wytrzymałość ich konstrukcji, w tym dynamiczna, związana z ruchem w kierunku pionowym nosidła obciążonego masą dziecka i zamocowanego na tułowiu poruszającego się opiekuna.
W publikacji przedstawiono wyniki pracy dotyczącej badań wytrzymałości konstrukcji nosideł miękkich, przeprowadzonej z wykorzystaniem autorskiej procedury badawczej. Badaniami objęto nosidła wprowadzane na rynek polski w latach 2012–2018. Przeprowadzone badania pozwoliły na identyfikację rodzajów uszkodzeń nosideł miękkich, które mogą powstawać podczas ich użytkowania oraz wskazanie parametrów konstrukcji wymagających zmian.

Introduction

Baby carriers are used for moving the babies and toddlers usually carrying them in a vertical position, attached to the carer's torso. Such a method for carrying the children enables a carer hands-free operation during daily activities and ensures close contact with a child at the same time [1, 2]. It should be also mentioned that moving babies in carriers is recommended by orthopaedic doctors in the case of a hip dysplasia [3].

Baby carriers can be divided into two groups: framed back carriers and soft carriers. Framed back carriers equipped with a supporting frame are mainly used in hiking. The frame design allows for placing it vertically, without a fear of the frame tipping over, before the child is inserted in it. Framed back carriers are designed to carry children from 6 months of age who can sit without assistance.

Soft baby carriers (without a framed support) are mainly made of textiles, and they are lightweight and easy to be attached to the carer's torso (ties, clamps). They can be used even for newly born babies. Slings attached to the carer's torso and the baby carriers equipped with an attachment system based on straps and/or belts and/or clamps belong to this group. The soft carriers without leg openings are extremely popular. They are called the ergonomic carriers due to an even distribution of a child's weight around the carer's torso using the hip belt.

The baby carriers, if not properly designed and made of a material that is not tough enough can cause falling hazards and serious injuries. This has been confirmed by the US Consumer Product Safety Commission (CPSC). Within the years 2014–2015, respectively, 11800 and 9500 cases of injuries to children caused by using baby carriers were reported [4], which made 19.5% of all injuries associated with use of children articles [5]. The baby's fall from the carrier caused by an improper adaptation of the carrier design to the baby's size and weight or improper use of the carriers are the main reasons of injuries [6, 7]. Notifications of RAPEX system reported that, within the years 2014–2019, 14 models of baby carriers were withdrawn from the European market due to a possibility of a baby falling out of them [8]. At present, the tests of baby carriers are conducted in the accredited laboratories to increase the safety of their use and to eliminate the cases described above.

According to the Directive 2001/95/EC [9], the framed back carriers should meet the requirements of EN 13209-1 Standard, and the soft carriers with openings for legs – the EN 13209-2 Standard [10–12]. This is the main condition for accepting the carriers for selling on the European market. The above mentioned standards do not include the requirements for the most popular soft carriers without leg openings, i.e. slings and ergonomic carriers.

The results of the research project "The safety of using the soft baby carriers" realized at KOMAG, aiming at an assessment of the strength and durability of the soft baby carriers introduced to the Polish market within the years 2010–2018 are described in the light of the current requirements [13]. The author's testing procedure, an implementation of which would enable one to assess the strength of slings and the structure of ergonomic carriers is presented.

1. Materials and test methods

The project was realized in 4 stages, according to the algorithm presented in Fig. 1.

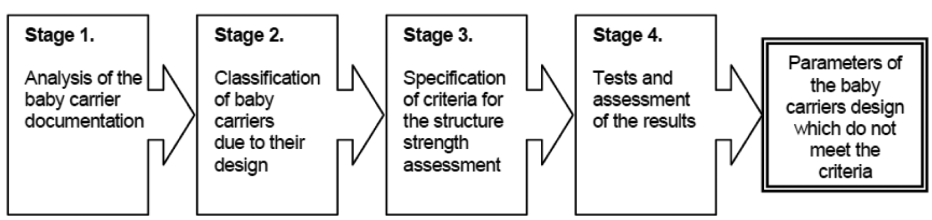

Fig. 1. Algorithm of the research work

At Stage 1, the documentation from the tests of baby carriers conducted within the years 2012–2018 in the accredited Laboratory of Material Engineering and Environment at KOMAG, which specialises in testing the children's articles [14], was analysed. A special attention was paid to those baby carriers, which were tested for the strength of their structure. Considering the limited scope of using the framed back carriers, only the soft carriers were analysed. Forty three soft carriers, which at Stage 2 were divided into the groups from A to C due to their design, were assessed, see Fig. 2 [15].

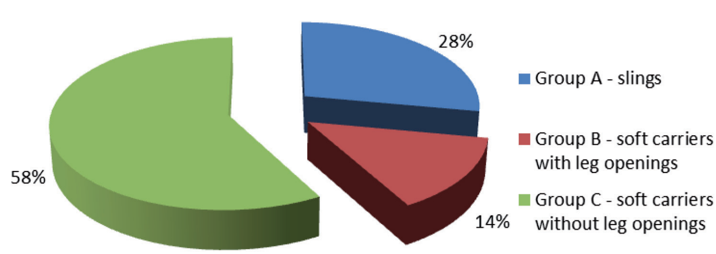

Fig. 2. Percentage share of each group of the tested soft carriers [13]

The slings in a form of a rectangular straps of cotton material with Jacquard or slant weaves of the basic weight from 220 to 280 g/m^2, of a length from 3.6 to 5.22 m, and a width from 0.51 to 0.72 m were classified to Group A. The slings differed in the method of attaching them to the carer's torso. 83% of them used a knot formed by the belt ends, and 17% had two rings for the material interlacing and tightening it.

The slings were intended for children from 3 to 14 kg or from 3 to 25 kg.

In Groups B and C, the baby carriers consisted of a panel made of cotton or polyester fabric of the basic weight from 200 to 280 g/m^2, filled with a polyurethane foam or with a polyester non-woven fabric as well as without any filling, profiled to the child's back and with straps and/or length-adjustable straps attached to it, equipped with clamps and/or ties, which served as a system for attaching and adjusting the carriers to the child's body and to the carer's torso. In Group B carriers, the attachment system consisted of two shoulder straps and a chest belt. In Group C carriers, it was based on the hip belt. The attachment system equipped with a hip belt allowed the load to be distributed evenly over the hips and shoulders of the carer. 25% of tested carriers of Groups B and C had an additional plastic stiffening panel. Panels of Group B carriers were integrated with the openings for the child's legs. The baby carriers of Group B were designed for children of weight from 5 to 13 kg, and the carriers of Group C were designed for children of weight from 3.5 to 20 kg or from 11 to 27 kg.

Design schemes of Groups B and C carriers are shown in Fig. 3.

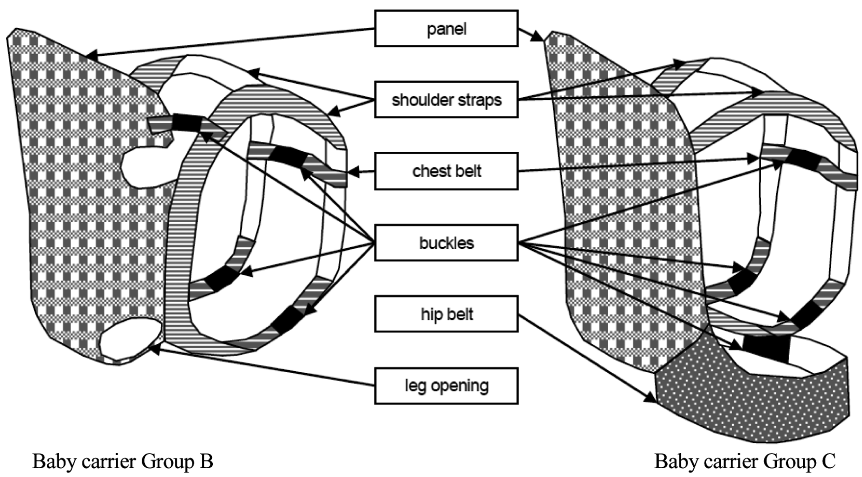

Fig. 3. Design scheme for baby carriers Groups B and C

In the next stage, the criteria for assessing the strength of soft carriers' design, based on the analysis of the standard requirements, were specified. The EN 13209-2: 2005 Standard, being in force in Poland from 15 April 2006 to 12 April 2016 and its amendment EN 13209-2: 2015 were taken into account [11, 12].

The analysis showed that the EN 13209-2 Standard only applies to Group B carriers and does not refer to Groups A and C carriers. The criteria for assessing the structural strength for Groups A and C are based on the safety requirements included in the CEN/TR 16512 Technical Report [16].

According to the above documents, the parameters that characterize structural integrity are as follows: static strength (for carriers of Groups A and C), the effectiveness of the carrier attachment system attaching the carrier to the carer's torso as well as fatigue strength (for Carriers A, B and C). Static strength means the resistance of the carrier structure to a permanent load with a mass of a child. Fatigue strength refers to the time-varying load during the cyclic lifting and lowering the child's mass in the soft carrier worn by the carer.

For the above design parameters, the criteria for an evaluation were selected, formulated in a descriptive or parametric form, as shown in Table 1. Damage to the soft carrier/carrier structure given in the criteria means breaking or tearing the material, ripping the seams, or breaking the tapes/straps and clamps.

Table 1. Criteria for assessment of design parameters of soft carriers

Group of soft carriers	Design parameters	Criteria for parameters assessment
A, C	Static strength	No damage to the structure of the carrier attached to the dummy after 24 hours of loading it with mass of a child (from 9 to 27 kg)
A, B, C	The effectiveness of the system for attaching the carrier to the carer's torso	Moving the components of carrier attachment system against the carer's torso W $\leq$ 20 mm after 100 cycles of lifting and lowering the dummy with a soft carrier loaded with mass of a child (from 9 to 27 kg)
A, B, C	Fatigue strength	After 50 000 cycles of lifting and lowering the dummy with the attached carrier, loaded with mass of a child (from 9 to 27 kg), there is no − damage to the structure of the soft carrier, − unclamping the system for attaching the carrier to the carer's torso

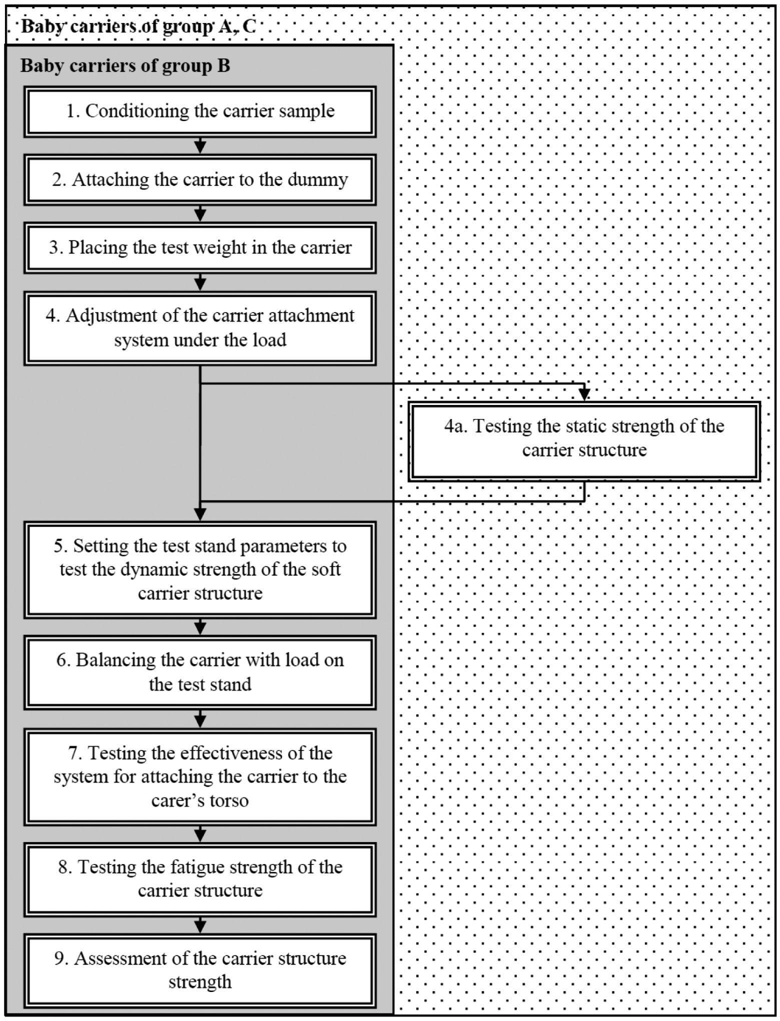

Fig. 4. Algorithm of the methodology for testing the strength of soft carriers

In Stage 4, the tests of the soft carriers' design strength were carried out according to the algorithm of the author's testing methodology including the tests of design Groups A and C of the carriers – Fig. 4.

Before testing, the slings and soft carriers were conditioned to eliminate the impact of fabric shrinkage being a result of washing and drying. The carrier, after conditioning, was attached to the dummy – Fig. 5, imaging the adult's torso.

A test mass equal to the mass of the maximum weight of a child, recommended by the manufacturer, was placed in the attached carrier. Then the components of the attachment system were adjusted so that the soft carrier adhered to the dummy's torso. For this purpose, the knot was tied and tightened up in slings A or their length was shortened by clamps. In B and C carriers, the length of the hip belt and/or shoulder strap and chest belt was adjusted using adjusters. For slings A and carriers C, the static tests of slings attached to the dummy and loaded for 8 hours were carried out. After the test, the condition of the slings' structure was assessed, identifying possible damage to the materials, seams, and parts of the attachment system to the carer's torso. The scope of tests of B carriers, according to the requirements of PN-EN 13209-2 Standard, did not include static strength tests.

Then, the dummy was placed in an automated test stand, where a movement of an adult carrying a child in a carrier when walking in difficult conditions was simulated (uneven floor – at a distance of about 30 km). The following test parameters were set and the fatigue strength test was started: frequency (2±0.2) Hz, and the amplitude of the dummy's vertical movement (120±5) mm. After starting the test, 10 cycles of lifting and lowering the dummy with a loaded carrier were realized to enable balancing it in the test stand.

After balancing the carrier in the test stand, the control lines on the length adjusters of the carrier attachment system straps to the carer's torso were marked, then again 90 cycles of lifting and lowering the dummy were realized. After their completion, measurements of shifting the strap adjusters of the

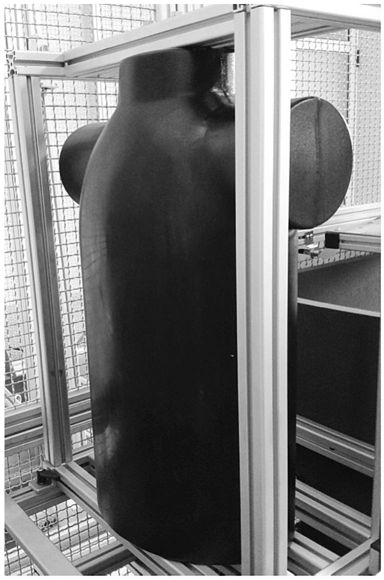

Fig. 5. Test torso

system for attaching the carrier to the carer's torso in relation to the marked control lines were taken. Then, the test was continued for the next 49900 cycles. After their completion, the condition of the soft carrier structure was assessed (possible tearing of fabrics, unclamping and breaking of straps).

The results of tests were evaluated in the light of the criteria set out in Stage 3. Based on the results analysis, the parameters of the carrier's design that should be corrected were indicated.

2. Results and discussion

Analysis of the test results showed the following damages:

- Textile rupture,
- Breakage of the shoulder straps,
- Breakage of the adjusters of the shoulder straps,
- Ripping the strap of the attachment system, and
- Unclamping of the attachment system.

Moreover, the following observations were reported:

- All of the tested carriers met the criteria specified for the static strength.
- The efficiency of the system for attaching the carrier to carer's torso, after the static test and after 90 cycles of lifting and descending the dummy with the carrier loaded with mass of a child on the test stand, was not sufficient in 16% of the tested carriers, including 8% in Group A, 17% in Group B, and 20% in Group C.
- 37% of the tested carriers were damaged during fatigue tests, including 33% in Group A, 50% in Group B, and 36% in Group C.

Rupture of the textile material was the most often reported damaged to the soft carrier, which was recorded in 24% of the soft carriers in Group A and 18% in group C. This damage occurred during the fatigue tests. A breakage of the shoulder strap was reported in 6% of the carriers from Group B. In Group C, ripping the straps of the system for attaching the carrier to the carer's torso (18%), unclamping the attachment system (24%), and a breakage of adjusters of the shoulder straps (12%) were reported.

It was found that the recorded damages were caused due to a use of the textile materials for manufacture of the soft carrier of inadequate strength for a child's mass. The slings of Group A in which the fabric was ruptured during the tests were made of cotton of the basic weight below 270 g/m^2, and the damaged panels supporting a child in the soft carriers of Groups B and C were made of cotton or polyester fabric of the basic weight below 230 g/m^2. The clamps and adjusters, being a part of the system for attaching the soft carrier to the carer's torso, which were broken or unlocked, were made of low fatigue strength plastics for a cyclic lifting and lowering of the child's mass in the carrier. Ripping the straps of the attachment system was caused due to a use of improper sewing technology (seams were too close to the fabric edge) or using too weak treads or improper selection of threads to the sewed material.

Conclusion

The necessity of performing many daily activities while taking care of a small child and, at the same time, ensuring the child's close contact with the carer, caused a widespread use of soft carriers from the first weeks of a child's life. State-of-the-art, breathable textile materials with a design following the fashion trends and easy-to-be-used as well as ergonomic attachment systems to the carer's torso inspired a development of their designs. These designs enabled the reduction of their weight, an increase in the ventilation of the child's support panels, and an improvement in the attachment method as well as comfort of wearing, due to an even distribution of the child's weight in the way that limits the load to the wearer's spine [17].

Because of the way of using soft carriers are (attached to the adult's torso), their design should guarantee the safety of the child being moved.

Despite the safety requirements, which are in force in the European market, concerning the above-mentioned products, still there are soft carriers that cause a risk of falling to a child due to an improper design [8].

The results of the research project showed that structure fatigue strength and the effectiveness of the system for attaching the soft carrier to the carer's torso are the parameters that determine the safety of the use of soft carriers. The original testing procedure adopted in the project with use of the adult torso model on an automated laboratory bench, simulating its movement with a carrier loaded with the weight of the child during fatigue tests, allowed assessing the strength of each component of the soft carrier. Damages found during the tests concerned the rupture of the textile material and seams as well as the fracturing or unclamping the components of the systems for attachment and adjustment of the soft carrier to the carer's torso based on clamps and plastic adjusters.

An analysis of the test results showed that the basic weight of textile materials used in carriers and having an impact on their strength was not adequate to the required carrying capacity of the carrier which is the child's body weight. Additionally, the plastics used to make clamps and adjusters had low tensile strength and did not withstand the load of body weight during cyclic lifting and descending. The indicated design parameters of soft carriers require an improvement.

The testing methodology, suggested by the authors, can be used for an assessment of the strength parameters of slings and ergonomic carriers, which are not included in the current normative regulations. The author's method will be implemented as the laboratory testing procedure for assessment of safety of using such carriers placed on the market. Results of the tests with use of this method will enable the manufacturers to improve the designs of their products.

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