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LIFE AS THE FACTOR OF TOYS SAFETY

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Abstract
The problem of product life as an important factor of toys safe use is considered. Main sources of hazards and their adverse effect to children health are characterized. The results of unwanted events associated with improper toy design and with its quality of manufacture as well as with use of inappropriate materials for toys production are discussed. Necessity of using the laboratory testing methods based on ageing process to predict changes in toys parameters during their use are pointed out. Features and criteria for assessment of toys life in the light of formal and legal requirements are specified. Considering experience of other scientists, presented in scientific publications as well as the results of the author studies, the innovative method for assessment of life of toys made of polymers is suggested.

Keywords
life, toys, hazards, safety of use.

Introduction

Toys are the products intended to be used by children to play. Toys manufactured with use of technical means, including manufacturing machines [1] are classified as technical objects. They may include simple as well as complex mechanisms that are used in the products and equipment intended for use by adults.

Technical objects life is defined as time passing from the beginning of its use till the moment of its malfunction, after which the technical object is not restored to its technical fitness due to economic or technical reasons [2].

Toys belong to non-renewable objects as in majority of cases their restoration to technical fitness by repair or replacement of damaged components is not economically justified. Determination of expected time of toy use without any malfunctions is important as regards its safety, when used by children.

Toy malfunction can lead to unwanted events, which can cause different types of hazards that can result in losses (injuries) i.e. loss of children health and life. Human losses can be immediate ones (accident) or delayed (chronic illness).

Effects of unwanted events are especially severe, when they concern children, the population which is most vulnerable to any hazards [3]. Data about the number of injuries and accidents, including the fatal ones, which result from use of toys by children, confirm that fact [4].

To eliminate the hazards associated with use of toys, they have to be designed and manufactured according to detailed safety requirements included in Toy Safety Directive No. 2009/48/EC (TSD), the harmonized standards published in the Official Journal of the European Union as well as in other legal acts [5–16].

The above mentioned requirements do not cover all reasons of hazards during use of toys e.g. change of toy strength in a result of wearing out and ageing of the material during use and storage. The process is especially important in the case of toys made of polymers, which are commonly used due to their easy processing and low costs [17–19]. In the literature we can find information that deterioration of properties of plastics result from ageing process, which intensifies under exposure to such environmental factors like UV radiation, temperature humidity etc. [20–26].

Deterioration of strength parameters of toys made of polymers in a result of ageing process is decisive as regards of their life i.e. time of their safe use.

In the harmonized standards, which are the tool for assessment of toys conformity with safety requirements, there are no methods for testing of impact of environmental condition on toys parameters associated with ageing of materials used for their manufacture. The need of including such methods to the standards is indicated in the research projects realized by the Technical Research Institute of Sweden [27].

Safety requirements do not oblige manufacturers to give information about the expected life of toys made by them. Thus, the manufacturers only analyze properties of the toys which are put on sale and do not consider change of toy parameters in the result of exposure to different environmental factors and the way of its use.

The necessity for determination of time of toys safe use by manufacturers is indicated in the publication.

The publication is divided into five parts. In the first part hazards to safe use of toys, especially the hazards resulting from design parameters as well as the risk of adverse health effects to children associated with them are given.

In the second part legal and formal requirements, which are the basis for designing, manufacture and commercialization of toys were analyzed. In the third part the features and criteria for assessment of toys life are specified with special attention paid to activating toys. In the fourth part the method for evaluation of life of toys made of polymers is suggested introducing a term of critical time of safety use of a toy. The last part summarizes the discussed problem.

Hazards to safe use of toys

The hazards to safe use of toys can be divided, depending on its character, into the following groups: physical, mechanical, chemical, electrical, fire, radiation and hygiene [28]. Each of the mentioned hazards can be described by a set of parameters and features, presence of which is associated with a risk of occurrence of unwanted events, which can have adverse effect to children health and life.

Physical and mechanical hazards belong to especially important risks due to their high rate of occurrence and serious health effects [29].

Source of such hazards are among others:

- improper shape and size of toys and their components, which can be swallowed by children, especially the younger ones,
- improper method of surface and edges finishing, what can result in presence of splinters and burrs as well as lack of protection of sharp protruding edges, including springs, wires, hinges and drive mechanisms,
- too long cords (e.g. in the toys intended to be stretched across beds and strollers as well as in toys to-be-pulled), made of too elastic materials,
- lack or not enough number and size of ventilation openings in toys the child can enter or can wear,
- improper dimension of toys foil packaging, which can be put on child's head ,
- too high kinetic energy of projectiles and arrows shoot by a toy,
- too high magnetic flux of the magnets used in toys, which after swallowing by a child can come together in a digestive system through organs walls (bowels walls),
- too high acoustic pressure emitted by a toy,
- too high temperature of accessible parts, which have a heat source,
- not enough static and dynamic strength as well as lack of toy stability,
- lack of protecting blockades or their not enough number in the toys with folding mechanisms (e.g. in strollers),
- lack of brakes or their not enough efficiency (e.g. in toy cars driven mechanically or electrically) as well as too high speed in the case of electric drives.

The above mentioned characteristics of toys can be a reason of the following injuries to children:

- partial or total obstruction of airways in the case of blocking of mouth and nose with foreign bodies [29–30],
- break of skin, including cuts and hurts with sharp edges or protruding components,
- suffocation in the result of insufficient supply of tissues with oxygen due to chocking strangulation or hanging,
- permanent damage to organ of vision in a result of direct contact with sharp objects or objects of high kinetic energy,
- deterioration or damage to hearing organ in the result of harmful acoustic stimuli of continuous or impulse noise of high intensity,
- burn in the result of contact with hot surfaces and objects,
- serious health complication caused by perforation of intestine in the case of swallowing of magnets with high magnetic flux,
- injuries to musculoskeletal system including contusions, sprains, break of bones and joints dislocation as well as brain concussion and internal bleed-

ing, including the fatal ones, in the case of fall from a height [31–33].

A risk of the above mentioned health effects is also associated with toys functions and with the method of their use. In this case the age of user is an important factor [34].

Available literature data indicate that children under 3 years are especially vulnerable to mechanical and physical hazards [3–4, 35]. Use of toys by children of such age is associated with a special kind of health risks, what is illustrated in Fig. 1.

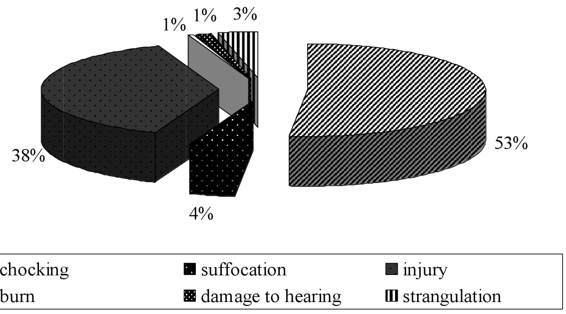

Fig. 1. Percentage share of each type of risk that occurs during use of toys intended for children under 3 years (own source on the basis of [36]).

Toys are divided according to CEN/CR 14379 classification [37] into 22 categories, from A to X considering their functions and characteristic features and into two age groups i.e. toys intended for children under and over 3 years.

Among the toys intended for children under 3 years we can distinguish the categories which have higher probability of adverse health effects than others. The following toys belong to these categories: activating toys, (category A), toys to be pulled and pushed as well as toys supporting learning to walk (category O), thematic toys (category P), toys for babies to watch, to grasp and/or to shake (category V) and toys to bear mass of a child (category W) [36].

Percentage share of each type of risk in the above mentioned toy categories is given in Fig. 2.

Chemical hazards, which can appear during use of toys, are also very important due to irreversible and latent character of health effects. Their source are the materials, which contain substances harmful to children like: heavy metals, carcinogen and mutagen substances as well as substances toxic to reproduction and the allergenic ones [38–39].

Chemical hazards are especially dangerous in the case of babies and toddlers, which are more susceptible to absorption and to retention of harmful substances.

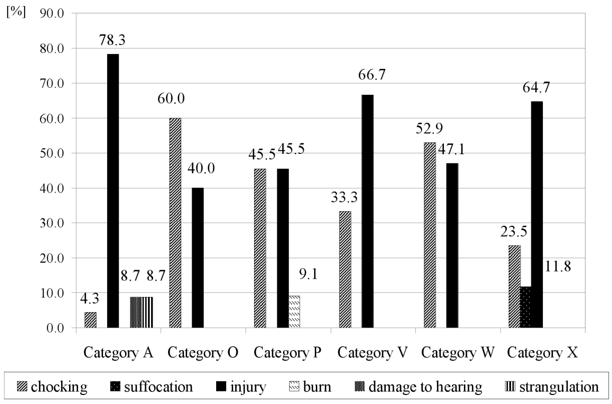

Fig. 2. Percentage share of each type of risk in the given toy category (source: own report on the basis of [36]).

Other types of risks to safety use of toys are as follows [34]:

- fire risk, resulting from use in toys the materials and substances, which cause fire in child environment, what can result in burns i.e.:
  - flammable materials or material that can be ignited in the case of contact with flame, spark or with other potential source of fire, which after catching fire burn quickly and spontaneously or they explode,
  - substances and materials, which after mixing can explode or which contain volatile substances that are flammable in a contact with air or can make explosive mixtures with air,
- electric hazard, that can occur during contact of a child with toys with electric supply of not proper parameters i.e.:
  - nominal supply voltage higher than 24 V,
  - insufficient insulation of live toy electric components,
  - too low mechanical strength of casings of electric supply sources (e.g. cell chambers) and electric connections,
  - insufficient protection of insulation of electric wires against mechanical damage e.g. cut by other toy components,
  - too low resistance to humidity as well as improper protection of electric components against water in toys, which are intended to be used in water as well as lack of proper shielding in the toys supplied from transformers, which can be cleaned with use of liquids,
  - toys overheating as well as too low thermal resistance of the components made of non-metallic materials,
  - access to batteries (without use of tools) in toys intended for children under 3 years.

Electric hazards mean a risk of electrocution, burn and in the case of swallowing of batteries, a risk of chocking and poisoning of a child.

- radiation, associated with use of materials containing radioactive elements, what can be a reason of acute radiation syndrome,
- hygiene, associated with use in toys or their packaging contaminated materials or materials that had already been in use and which are contaminated by harmful substances to higher degree than the new material, what can lead to poisoning or infection.

Legal and formal requirements

In order to limit the risks associated with the use of toys, their manufacturers should take into consideration the safety requirements specified in Annex II of 2009/48/EC (TSD) Directive [5] in the designing process and manufacture of toys.

Due to general character of these requirements, which do not specify any guidelines as regards design, material and useful features, the toy manufacturers should take into consideration the parameters included in the following harmonized standards:

- EN 71-1:2011. Safety of Toys. Part 1. Mechanical and physical properties,
- EN 71-2:2011. Safety of Toys. Part 2. Flammability,
- EN 71-8:2011. Safety of Toys. Part 8. Activating toys for domestic use,
- EN 62115:2005/A2:2011/AC:2011. Electric toys. Safety.

As regards chemical hazards the manufacturers should include the requirements specified in Item 3 of Annex II of 88/378/EEC Directive and in the standard harmonized with it, among other in: EN 71-3:1998/A1:2001/AC:2004 Standard – Migration of certain elements.

Acceptable concentrations of dangerous substances in toys are specified in REACH Regulation [8].

In the case of chemicals classified as carcinogenic, mutagenic and toxic to reproduction (CMR), the requirements are given in the EN 71-9+A1:2008 Standard – Organic chemical compounds. Requirements.

Before commercialization of toys the manufacturers should carry out safety assessment procedure to make analysis of physical, mechanical, chemical, electric, fire, radioactivity and hygiene hazards as well as they should assess eventual exposure of a child to the identified hazards [34].

It should be noted that safety requirements for use of toys refer to new toys used by children as intended and in the way possible to be predicted at typical behavior of children.

However, the requirements do not include changes of toy parameters with time and with conditions of use.

Features and criteria of assessment of toys life

Toy technical condition as well as function, method and condition of use decide about toy's life. Initial technical condition of toys is described by a set of individual properties shaped during designing and manufacturing processes. Toys properties can be divided into groups of primary features and physical features. They can be measurable or non-measurable.

There are the following primary features:

- geometric parameters e.g. shape, length, width, height, thickness, tread and diameters of openings,
- surface condition (shape errors, corrugation, roughness), e.g. crushes, folding, burrs, sharp edges,
- chemical composition and a material structure.

The following toy parameters associated with functions realized by it belong to the group of physical features:

- strength,
- mechanical,
- thermal,
- magnetic,
- electric,
- acoustic,

During use the toys are subjected to different impacts including:

- external ones, associated with environment in which the toys are used e.g. air temperature as well as with aware or unaware activity of a child, i.e. so-called anthropotechnical factors,
- operational ones, associated with a function realized by the toy e.g. bearing a mass of the child.

In the result of action of the above mentioned factors the initial features of the toy change. In the majority of cases the changes have adverse character and they can lead to malfunction (damage) of toys what can threaten safe use of the toy.

The rate of changes, which are of random character, depends on the level of external and operational impacts, on initial technical conditions of the toy and on time which passed from the beginning of its use.

Prediction of changes to technical conditions of the toy, aiming at determination of required life of a toy, that is the period of its safe use, requires creation of sets of fitness features, which are suitable

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for each toy type and category and then determination of assessment criteria (accepted values). Any exceedances of the values of the given fitness feature can cause toy malfunction, which threatens its safe use.

At present technical condition of toys is assessed upon the criteria specified in toys safety standards [9]. They are the guidelines used in designing and manufacture of toys.

The example of set of features and criteria for assessment of activating toy intended for children under 3 years belonging to two categories: toys to bear mass of a child (category W) and activating toys (category A), is given in Table 1.

Table 1
List of features and criteria for assessment of activating toy intended for children under 3 years [own source].

Group of features	Type of feature	Type of the parameter	Requirements/limit values
Primary features	Geometric parameters	geometric dimensions	separable components do not entirely fit in the small parts cylinder
			height of potential free fall of a child measured from the floor to the sitting place <600 [mm]
	Surface condition	condition of toys and used materials	toys and used materials are clean and free of parasites, there is a possibility of cleaning and washing in the case of textiles
		condition of edges and surface	sharp metal edges unaccessible
			edges and surface of components made of polyethylene are free of burrs that can cause injuries and abrasion, edges are rounded
Physical features	Strength parameters	strength to torsion	during standard test with use of torque (0.340±0.01) Nm none of small components were separated and any sharp edges and points became available
		tensile test	during standard tensile test with use of force (90.5±0.3)N none of small components were separated and any sharp edges and points became available
		drop test	during standard drop test from the height (850 ±10)mm none of small components were separated and any sharp edges and points became available
		impact test	during standard impact test with mass (1.00±0.01)N thrown from height (100±2)mm none of small components were separated and any sharp edges and points became available
		stability test	during standard static strength test by loading with mass (25.0±0.1) kg the toy placed on the ramp of inclination $(10\pm1)^0$ C did not tip over
		static strenght	during standard static strength test by loading with mass (25.0±0.1) kg and (49.8 ±0,2) kg the toy did not break and any sharp edges and points became available
	Flammability	flammability of materials used in toy manufacture	toy is not made of celluloid, of the materials of fleece surface, which after coming in touch with flame ignite and of the flammable solids as well as it does not contain any flammable gases and fluids as well as prohibited gels
		rate of flame propagation	rate of flame propagation in a toy textile material <30mm/s
	Chemical parameters	migration of certain elements: antimony Sb, arsenic As, barium Ba, cadmium Cd, chromium Cr, lead Pb, selenium Se, mercury Hg	migration of elements from toy material: Sb<60 mg/kg, As<25 mg/kg, Ba<1000 mg/kg, Cd<75 mg/kg, Cr<60 mg/kg, Pb<90 mg/kg, Hg<60 mg/kg, Se<500 mg/kg
		content of phthalates: diethylhexyl (DEHP), dibutyl (DBP), benzylbutyl (BBP)	total content of DEHP, DBP, BBP phthalates in toy polymer material <0,1%
		content of phthalates: diisononyl (DINP), di-n-octyl (DNOP), di-isodecyl (DIDP)	total content of DINP, DNOP, DIDP phtalates in toy polymer material <0.1%
		cadmium content (Cd)	Cd content in toy polymer material <0.1%

The mentioned categories: W and A have level of chocking and injury risk higher than in other types of toys (Fig. 2). The analyzed toy of dimensions: 800 mm × 300 mm × 400 mm, is made of polyethylene. The toy weight is 2.6 kg. The toy consists of a body with one seat for a child and a front part of the toy with handle bars to be grasped by a child (Fig. 3). The way of use of the toy consists in setting it into motion (rocking) by strength of a child or adult muscles.

Fig. 3. Activating toy to bear mass of a child [own source].

The table does not contain parameters of properties of the materials used for toy manufacture and which decide about toy life i.e. time of its safe use. These parameters should be included to the group of the primary parameters.

Consideration of the properties of the material in an assessment of toy's technical condition is especially important in the case of toys made of plastics, because they change their features over time under influence of external factors such as: ambient temperature, light, radiation, oxygen, humidity and reactive chemical compounds.

These factors initiate and accelerate adverse physical and chemical processes in polymer material such as: destruction, degradation, depolymerization, crystallization and recrystallization as well as migration of auxiliary agents e.g. plasticizers [19].

Activating toys used outdoors e.g. in gardens and playgrounds are especially exposed to sudden changes of weather conditions and long-term static and dynamic loads associated with the way of their use. Such situation causes acceleration of ageing of toy materials leading to deterioration and weakening of their structure and finally to damage of the toy.

The toys made of polymers should be tested as regards their ageing by the method of artificial ageing, the so-called accelerated ageing [40–44], in the atmosphere of the specified parameters, which are representative for the conditions in which the toys will be used. Time of ageing test should refer to the time of natural ageing of polymer material. It was assumed that minimal period of ageing of plastics in natural conditions is 5 years [45].

After the ageing tests the toys should be tested again as regards their mechanical properties, which will verify the strength parameters whether they meet safety criteria specified in Table 1.

Results after ageing test should be compared with the results before the ageing test. Thus limit values specified in the safety standards for each strength parameter can be accepted as the criterion for assessment of life of toys made of polymer material.

Method for estimation of life of toys made of polymers

Characteristics of changes of strength parameters of the materials in time, so-called diagrams of aging kinetics, can be used to determine toy's life, what is the time of its safe use (Fig. 4) [46].

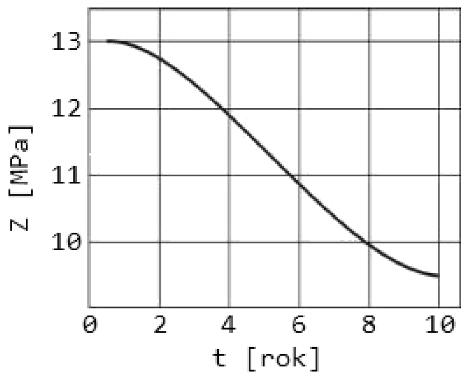

Fig. 4. Diagram of kinetics of ageing of PA6 polyamide, where Z – fatigue strength, and – time of ageing [46].

Curves of characteristics are developed on the basis of the ageing test results for different types of polymers and products made of polymers. Such tests are carried out mainly for plastics used in the industry, especially for manufacturing of pipelines, cables and other constructional components. Information included in the literature, which is available to the author, shows close similarity of shape of the diagrams of ageing kinetics for different types of polymer materials, including polyethylene commonly used for production of toys as well as polyamide [46–47].

It is possible to determine the time t_0, which is a critical time of safe use, on the basis of the diagram of kinetics of material ageing and minimal strength Z_0 specified by the toy manufacturer and determined on the basis of safety criteria and shape, geometrical parameters of the toy as well as planned way of its use.

Due to error of the method for determination of ageing characteristics of the polymer materials on the basis of results of speeded up ageing tests, which are realized in artificial conditions, which differ from the conditions of natural ageing, and due to stochastic character of ageing process, acceptation of determined time t_0 as recommended time for toys use would be associated with high risk of their damage during use. It is thus indispensable to assume the safety margin.

For that purpose, a concept of probability of damage of the toy during use was introduced. It should be noticed that the toy, which meets the safety criteria, at the moment when it is given to use, has a probability of damage equal to 0. After exceeding the time t_0 the probability of damage is equal to 1.

Aiming at determination of distribution of probability of damage of toy during use, at first the characteristics of ageing of the polymer material in time should be determined in an analytical way.

The shape of curve of changes of fatigue strength Z in time t, which is presented in Fig. 4, can be described by the equation (1) [47]:

$$Z\left(t\right) = A + B\phi\left(u\right) \tag{1}$$

where A and B – constants,

ϕ(u) – density of probability of normal distribution described by equation (2)[47].

$$\phi\left(u\right) = \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{u^2}{2}\right) \tag{2}$$

$$u = \frac{t - t_r}{\sigma} \tag{3}$$

where u – standardized random variable, $t_{r.}$ – average ageing time resulting from normal distribution, σ – standard deviation of a random variable.

Values of constants A and B are defined as:

A – the least value of fatigue strength as regards physical and chemical properties of the material in time approaching infinity t_∞,

B – measure of intensity of the aging process determined by the least squares method or by the least errors method.

In the work [46] it has been proved that normal distribution enables to determine the parameters of equations (1) and (2) by iteration method with approximation errors lower than in the case of other random distributions.

Approximation with use of spline functions is another method for determination of characteristics of material ageing [48]. This method enables approximation of ageing at each point of time variation t interval with use of third-degree polynomial. It simplifies calculations and determination of material ageing process at any point.

Knowing analytical form of function $Z(t)$ determined with use of correlation (1) or spline functions, the function of density of probability of toy damage f_B (4) during its use can be determined [49], when meeting the following axioms of probability distribution:

- axiom I: Probability of any event is non-negative number.
- axiom II: Probability of sure event is equal to one.
- axiom III: Probability of the sum of separable events is equal to the sum of probabilities of these events.

It is possible to determine a cumulative distribution function F_B (5) on the basis of density function f_B (4):

$$f_B = \begin{cases} 0;\ t < 0 \\ \dfrac{Z_m - Z(t)}{Z_m t_0 - \int\limits_0^{t_0} Z\left(t\right)dt} \quad ;0 \le t < t_0 \\ 0;\ t \ge t_0 \end{cases} \tag{4}$$

where Z_m – maximal value of function Z(t) in the interval <0, t_0)

$$F_B(t) = \int\limits_0^t f_B(t)dt. \tag{5}$$

Graphical determination of density function f_B is illustrated in Fig. 5.

Shape of density function f_B determined by equation (4) is presented in Fig. 6. While approaching to time t_0 the number of events consisting in mechanical damage of the toy increase proportionally with decrease of its strength $Z(t)$.

On the basis of known density function f_B and accepted probability of toy damage P_D, assumed by toy designer, it is possible to calculate the time of safe use of toy t_D, which meets the following condition:

$$F_B\ (t_D) = P_D \tag{6}$$

Taking into account (5):

$$F_B\left(t_D\right) = P_D = \int\limits_0^{t_D} f_B\left(t\right)dt. \tag{7}$$

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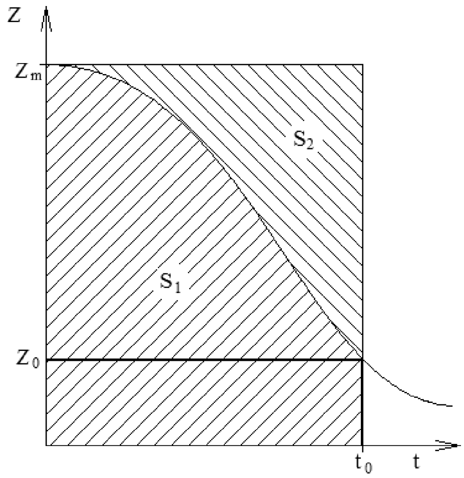

Fig. 5. Graphical interpretation of determination of density function f_B depending on function $Z(t)$: S_1 – surface under the curve $Z(t)$ in the interval $< 0, t_0)$, $S_2 = S_1 - Z_m t_0$ [own source].

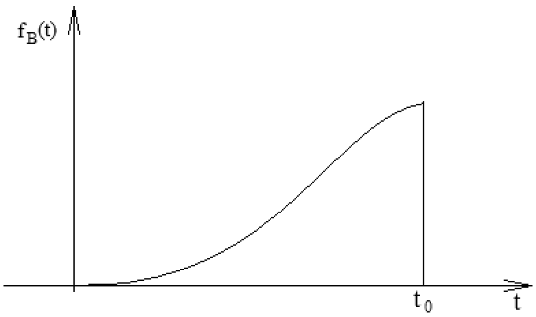

Fig. 6. Shape of density function f_B [own source].

The knowledge of diagrams of ageing kinetics enables determining the time of safe use t_D, i.e. life of toy, with a probability of toy damage assumed by the manufacturer.

Summary

High level of safety use of toys as the products intended for a group of consumers very sensitive to hazards, i.e. for children, requires focusing on the problem of change of toys properties in time and under action of different environmental factors.

That is especially important in the case of toys made of polymers, which undergo aging process which has a negative impact on their strength parameters. Improper selection of material and not considering the changes in its structure and properties in a result of aging process can have a significant impact on the time of toy safe use, i.e. on toy life.

Extension of toys life by a selection of proper materials for their manufacture, which are adequate, according to the current standards and regulations, to the environmental conditions, is not in the interest of manufacturers. The manufacturers want to minimize production costs and first of all they follow the costs of raw materials used for toys manufacture.

Safety standards, which are the guidelines for designing and manufacturing of toys as well as for verification of their conformity to the requirements, do not specify testing methods enabling assessment of change of toys parameters in time. Because of that only initial technical condition of toys is assessed. Assessment of change of toys parameters in time of their use requires introduction of methods based on aging tests, which for example are used in the automotive industry.

The method for determination of toys life – safe time of toys use, which is based on diagrams of aging kinetics and probability theory, suggested by the author, can be an analytical tool for selection of toys material. However, it requires verification of the results of aging tests of toys made of polymer materials.

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