Ageing and wear in polymeric child articles
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Abstract

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This report targets child use and care articles, toys and playground equipment. These products will in this report collectively be referred to as ‘child articles’.

It is the authors’ experience that polymers are getting more and more frequent in child articles, probably since they are cheaper and in many ways easier to process than metals. This is not an unwanted development in itself, but the choice of material has to be carefully made since the material properties of polymers vary greatly depending on the type and amount of additives and this can not be assessed visually. In addition they degrade with time due to environmental influence. To verify the properties of a polymer the material has to be tested.

One of the challenges with polymers is that they all have a limited lifetime. They degrade over time and might lose almost all their strength, leading to material failure and, in the worst case scenario, accidents. It is a fact that accidents happen due to material failure, although it is hard to trace the true cause in accident statistics. In this report the term ‘ageing’ will be used for chemical degradation of the material structure due to light and/or heat exposure and ‘wear’ refers to mechanical degradation as a result of mechanical stress and contact. The current regulation covers property changes in polymers during the lifetime of a product insufficiently, if at all. Ageing of materials is virtually non-existing in existing child article standards.

During its life a product is subjected to all kinds of environmental factors which more or less lead to reduction of function of the product. All products get worn, in one way or another, when used and the surrounding environment affects the material of the product. These effects are greater or lesser depending on usage and the harshness of the surrounding environment, as well as material choice and other qualities of the product. Therefore the material and processing have to be chosen based on the knowledge of the environment in which the product will be used as well as the expected lifetime. This process is called environmental design or environmental engineering.

In order to simplify the material selection process when a product is developed, it is recommended to compose a material qualification system for child articles. This system can preferably be based on existing systems from other industries.

This study recommends that the requirements and test methods proposed in Chapter 5 are considered when new standards for child articles are being developed or when existing standards are being revised. It is also recommended to perform a risk analysis to identify the hazards of a product.

Key words: ageing, aging, wear, child use product, child care product, toy, polymer, child article

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Contents

Abstract 3
Contents 4
Preface 5

1 Introduction 7

2 Current regulation and standardisation 8

3 Environmental factors and their consequences 11
  3.1 Environmental design 11
  3.2 Environmental factors relevant to polymers 12
  3.3 Material phenomena 12
  3.4 Reduction of performance 13
  3.5 Reported accidents due to material failure 13

4 Actions to minimize reduction of performance 15
  4.1 Expected lifetime 15
  4.2 Testing and requirements – discussion 15
    4.2.1 Light exposure – outdoor products 17
    4.2.2 Light exposure – indoor products 18
    4.2.3 Heat exposure 19
    4.2.4 Fracture characteristics 20
    4.2.5 Wear – simulated use 20
  4.3 Material qualification systems 21

5 Proposals of requirements and test methods 23
  5.1 Age characteristics 23
    5.1.1 Light exposure – outdoor products 23
    5.1.2 Light exposure – indoor products 24
    5.1.3 Heat exposure 24
    5.1.4 Alternative evaluation methods of age characteristics 25
  5.2 Fracture characteristics 25
  5.3 Wear – simulated use 25
  5.4 Material qualification system 26

6 Conclusions 27

7 References 28
Preface

This report addresses people involved in the preparations of standards and people at authorities and test institutes as well as designers and manufacturers. The report presents suggestions of requirements and test methods for polymeric child articles, as well as motivations to these.

This study has been commissioned to SP Technical Research Institute of Sweden by Dr Franz Fiala at the Österreichisches Normungsinstitut. The work has been carried out at the technical department ‘Building Technology and Mechanics’ at SP and has also involved experts from the department ‘Materials Technology and Chemistry’.

Many different child articles are tested by SP according to European standards on a regular basis. These tests involve mechanics, chemicals, flammability and sound as well as child safety in general. SP is also active in different standardisation groups concerning child articles and pursues development/research projects in the field.

The authors would like to sincerely thank Dr. Franz Fiala at the Österreichisches Normungsinstitut, for initiating and supervising this project.

Borås, Sweden in September 2008

Karin Lundh
1 Introduction

This report targets child use and care articles as defined by the European Committee CEN/TC 252 Child use and care articles [44], toys as defined by the European Toy safety directive [2] and/or in the Toy standard EN 71 [4] and playground equipment as defined in EN 1176 [15]. These products will in this report collectively be referred to as ‘child articles’.

It is the authors’ experience that polymers are getting more and more frequent in child articles, probably since they are cheaper and in many ways easier to process than metals. This is not an unwanted development in itself, but since the materials have very different qualities, caution has to be taken when changing the material of (part of) a product. This is especially true since the material properties of polymers vary greatly depending on the type and amount of additives and this can not be assessed visually. Two products can look identical even though they are made of materials with very different properties. The only way to tell the difference may be the price. But a high price is never a guarantee for good quality. This is obviously challenging for consumers. To verify the properties of a polymer the material has to be tested. Keeping all this in mind it is alarming that polymers are becoming more frequent in safety critical details, such as locking mechanisms and load carrying parts of a structure.

One of the challenges with polymers is that they all have a limited lifetime. They degrade over time and might lose almost all their strength, leading to material failure and, in the worst case scenario, accidents. It is a fact that accidents happen due to material failure, although it is hard to trace the true cause in accident statistics. In this report the term ‘ageing’ will be used for chemical degradation of the material structure due to light and/or heat exposure and ‘wear’ refers to mechanical degradation as a result of mechanical stress and contact through normal use. The current regulation covers property changes in polymers during the lifetime of a product insufficiently (if at all), lacking detailed provisions for the implementation of related requirements. Ageing of materials is virtually non-existing in existing child article standards.
2 Current regulation and standardisation

Child use and care articles, i.e. not toys, are under the jurisdiction of the Product safety directive [1]. This directive states that a product shall be considered safe when it conforms to a European standard which has been published by the Commission in the Official Journal of the European Communities. If there are no specific European regulations, a product shall be presumed safe when it conforms to the specific rules of national law where the product is marketed.

If, for a certain product, there is no standard published in the Official Journal of the European Communities implementing the Product safety directive, the product obviously still has to comply with the safety requirements of the directive, which then must be interpreted by the manufacturer. When assessing the safety of a product in these circumstances, the following shall be taken into account:

- other European/national standards
- recommendations from the Commission
- the state of the art and technology
- reasonable consumer expectations concerning safety

The Product safety directive defines a ‘safe product’ as any product which does not present any risk or only a minimum acceptable risk for the safety and health of persons, under normal or reasonable foreseeable use, including duration. When this is assessed, the categories of consumers at risk shall be taken into account and children and elderly shall be particularly considered.

This definition implies that a risk analysis should be performed, which should cover the life span of the product. It is also interesting to note that the safety and health of children should be prioritized.

The Toy directive of 1988 [2] does not take into consideration ageing of materials. It states that a toy must meet the safety and health conditions “in the condition in which it is placed on the market”. There is however a proposal for a new toy directive [3], in which there is a safety requirement stating “Toys placed on the market shall comply with the essential safety requirements during their foreseeable and normal period of use.” The proposal also introduces a new obligation to perform an analysis of the hazards a toy may present.

The proposed changes of the Toy directive thus require that a product shall be safe during its expected lifetime, but to make sure that the intended effect is achieved, these requirements need to be implemented in the Toy standard, EN 71 [4]. As of now, the Toy standard only requires that materials shall be free from infestation.

Requirements for aging of materials are virtually non-existent in European product standards for child articles. A few examples of the existing material requirements are listed in Table 1 below. The product standard for child seats for cycles [28] requires a salt spray test for protection against corrosion. The product standards of several other products, e.g. playpens [24], require that metal within reach of the child shall either be made of “corrosion resistant materials” or be ”protected against corrosion”, but there is no reference to a test to verify this.

Several products, e.g. changing units [23] and playpens [24] are required to be free from decay and insect attack if they are made of wood, wood based materials or materials of vegetable origin. This shall be investigated visually.

It is interesting to note that infestation by vermin is covered to a much higher degree than ageing of materials.
<table>
<thead>
<tr>
<th>Standard no. and product</th>
<th>Decay and insect attack (1)</th>
<th>Test method</th>
<th>Corrosion (2)</th>
<th>Test method</th>
<th>Ageing and wear</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 716 Children’s cots</td>
<td>yes</td>
<td>-</td>
<td>yes</td>
<td>not specified</td>
<td>no</td>
</tr>
<tr>
<td>EN 1466 Carry cots</td>
<td>yes</td>
<td>visual inspection</td>
<td>no</td>
<td>-</td>
<td>no</td>
</tr>
<tr>
<td>EN 1888 Prams</td>
<td>no</td>
<td>-</td>
<td>no</td>
<td>-</td>
<td>partly (3)</td>
</tr>
<tr>
<td>EN 1930 Safety barriers</td>
<td>yes</td>
<td>not specified</td>
<td>no</td>
<td>-</td>
<td>no</td>
</tr>
<tr>
<td>EN 12221 Changing units</td>
<td>yes</td>
<td>visual inspection</td>
<td>yes</td>
<td>not specified</td>
<td>no</td>
</tr>
<tr>
<td>EN 12227 Playpens</td>
<td>yes</td>
<td>not specified</td>
<td>yes</td>
<td>not specified</td>
<td>no</td>
</tr>
<tr>
<td>EN 12790 Reclined cradles</td>
<td>no</td>
<td>-</td>
<td>no</td>
<td>-</td>
<td>no</td>
</tr>
<tr>
<td>EN 14036 Baby bouncers</td>
<td>no</td>
<td>-</td>
<td>no</td>
<td>-</td>
<td>no</td>
</tr>
<tr>
<td>EN 14344 Child seats for cycles</td>
<td>yes</td>
<td>not specified</td>
<td>yes</td>
<td>ISO 9227, ISO 4628-3</td>
<td>no</td>
</tr>
<tr>
<td>EN 71 Toys</td>
<td>yes</td>
<td>visual inspection</td>
<td>no</td>
<td>-</td>
<td>no</td>
</tr>
<tr>
<td>EN 1176 Playground equipment</td>
<td>no</td>
<td>-</td>
<td>yes (4)</td>
<td>not specified</td>
<td>partly (4)</td>
</tr>
</tbody>
</table>

(1) Applies to wood, wood based material and material of vegetable origin
(2) Applies to metals within reach of the child
(3) Wear is covered to some extent through sequential testing
(4) Materials shall be chosen and protected in such a way that the constructional stability is ensured and this should be given special attention when the products are to be used in extreme climate or weather conditions. Composites should be UV resistant. Swings shall be cyclically tested.

The product standard for prams and strollers, EN 1888:2003 [19], covers wear of the product to some extent through sequential testing. There are several tests which in effect act as pre-conditioning tests, i.e. they simulate wear through normal use. The prescribed test order requires that these tests are performed before the corresponding requirements are controlled. For instance, before the parking break is inspected it shall be engaged and disengaged 200 times. This is one way of trying to make sure that the product still meets the requirements after some use. Also, one of the first tests a pram is subjected to is the Irregular surface test, in which the pram completes 36 000 cycles on a conveyor system with four obstacles. This test precedes the controlling of safety requirements. However, EN 1888 is under revision and the proposal is to move the Irregular surface test to the end...
and with that the pre-conditioning effect will be lost [20]. The proposal is to change the requirements of the test to “There shall be no visible damage to the vehicle.” and “The vehicle shall not collapse, the locking mechanisms and the attachment devices shall still function as intended.”

The product standard covering playground equipment, EN 1176 [15], states that swings shall be subjected to a cyclic test in which they perform 100 000 cycles of a pendulum movement of minimum 120 degrees with a loaded seat. This is virtually the only reference to wear testing. Ageing is partly covered by some general requirements on the materials stating that they shall be chosen and protected in such a way that the constructional stability of the product will not be significantly affected before the next inspection. The choice of material should be given special attention when the products are to be used in extreme climate or weather conditions. It is also required that composites should be UV resistant. No test method is however specified for any of these requirements.
Environmental factors and their consequences

During its life a product is subjected to all kinds of factors which more or less lead to reduction of function of the product. All products get worn, in one way or another, when used, and the surrounding environment affects the material of the product. These effects are greater or lesser depending on usage and the harshness of the surrounding environment, as well as material choice and other qualities of the product. Therefore the material and processing have to be chosen based on the knowledge of the environment in which the product will be used. This process is called environmental design and will be discussed briefly in Chapter 3.1.

The environmental factors (sun light, heat/coldness, dryness/humidity, wear, solvents…) lead to material phenomena (brittleness, wear, fatigue, relaxation …) which in turn lead to reduction of function of the product (looseness, fracture …). In many cases the chain ends here or hopefully even earlier, but often the material phenomena are undetectable by the consumer and the reduction of function may not be great enough to be attended to. In that case the consequence is an incident or accident. Chapters 3.2 through 3.5 will briefly discuss the different steps of the chain.

3.1 Environmental design

The life of the product varies greatly with the environment. Products must either be protected from environmental stresses or endure them. Either way environmental factors need to be considered when the product is being developed, engineered and produced. The influence shall be minimized, bearing in mind the expected life span of the product. It is important to note that it is impossible to completely remove the influence of environmental factors.

In order to achieve environmental endurance there are three steps to follow. Firstly, the environment in which the product will be used must be defined and analyzed. Secondly, a specification of the requirements of the product shall be produced which implies that the expectations on the product must be clear. Lastly, instructions of verification need to be defined, i.e. what tests should be performed to show that the requirements are met? A detailed description of the methodology of environmental engineering is presented in the Environmental Engineering Handbook [48]. Here only a short overview is given.

When analyzing the environment in the first step of environmental design, different categories of environmental factors have to be considered; chemical, biological, climatic, mechanical and electrical. This is normally assessed over the entire life cycle of the product. When assessing the environmental factors it shall be noted that not all factors are design restrictive in the use phase of the life of a product. This means that some factors are tougher on the product in the transport or storage phase than when the product is being used. For instance, vibrations might affect a certain product during transport as well as during use, but even though the vibrations during use are relevant, they might affect the product less than those which arise during transport. This implies that the vibrations during transport restrict the design of the product. Not all factors are even relevant in all phases of the life of a product. Corrosion is for example more or less always present. But compared to usage in salt water, the corrosion during transport and storage would not be considered relevant. The relevancy of different factors has to be assessed for each product individually. An example of environmental factors for a certain (not specified) product is presented in Table 2.
The spectrum of child products is very broad and the different products are subjected to very different conditions in terms of expected lifespan, usage, environmental factors, and so on. To achieve environmental endurance, this process has to be gone over for each product category, like for instance prams or high chairs.

Table 2  Example of a compilation of relevant environmental factors for a certain (not specified) product

<table>
<thead>
<tr>
<th>Category</th>
<th>Factor</th>
<th>Assessment*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>Corrosion</td>
<td>D</td>
</tr>
<tr>
<td>Biological</td>
<td>Mildew</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>Insects/other vermin</td>
<td>D</td>
</tr>
<tr>
<td>Climatic</td>
<td>Heat</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Cold</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Moist</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>Sunlight</td>
<td>D</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Impact</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Vibrations</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Abrasive wear</td>
<td>D</td>
</tr>
</tbody>
</table>

* R = relevant, but not design restrictive  
D = design restrictive

3.2  Environmental factors relevant to polymers

All polymers are sensitive to sunlight and heat. Even indoor products are exposed to sunlight, if so to a lesser extent, and heat is always present. Polymers are also sensitive to coldness. When the temperature drops too low, the qualities of the material change.

Some polymers absorb water and behave differently depending on the level of their water content. Organic solvents, like white spirit or acetone, can also affect the properties.

Any mobile parts of a product will be subjected to wear when the product is used, especially parts which come in contact with one another.

3.3  Material phenomena

Sunlight and heat break the chemical bonds of the polymeric chain, making the material brittle, with a loss of strength. At the same time, absence of heat might also affect the material. When the temperature drops too low, the material becomes glass-like, i.e. hard and brittle. This often happens very suddenly, at a specific temperature. The critical temperature, the ‘glass temperature’, varies with different polymers and can be changed by additives.

The mechanical properties of water absorbing plastics, e.g. polyamides, change with the water content. Some polyamides can absorb about 5 % water and have splendid mechanical properties at this level of humidity. The water works as a plasticiser and generates good impact resistance. If materials of this type are stored at low relative air humidity they dry and the materials become more brittle.

Some construction plastics, e.g. polycarbonates, crack much easier when the surface layer absorbs organic solvents.
When the load on a construction is large enough the structure breaks. But also at lower loads the material becomes damaged, even if not visually detectable. When repeated, these forces may initiate cracks, which propagate every load cycle. This is known as fatigue. After some time the crack reaches its critical length, which may still be short enough to stay undetected, and it propagates uncontrollably and the material fractures.

Mobile parts grinding against each other lead to cracks and eventually loss of material or fracture. Obviously this also affects the strength of the product.

When a polymer is stretched for a long time the material tries to release the tension by stretching the molecules, i.e. the stress is reduced but the strain stays the same. This phenomenon is known as relaxation.

Wear, e.g. friction between two moving parts of a product, can lead to material loss. An example of this phenomenon could be a metallic chain of a swing that “eats through” the plastic chip connecting it with the stand.

3.4 Reduction of performance

The material phenomena discussed above implies reduction of the performance of the product. This reduction could be harmless but irritating, like a change in colour. But it could also increase the risk of an accident, like an increasing looseness of joints, (e.g. the locking mechanisms of a foldable children’s cot are not as distinct after some use), a fracture on a load carrying part of a structure (e.g. a handle of a stroller is suddenly disconnected from the stroller) or any of an infinite variety of scenarios.

To minimize the risk of these scenarios, it is important to design each product, including engineering, material choices and processing, with respect to its presumed life. And it is even more important to use a large enough safety margin.

It is desirable to detect the damage of the product before it leads to an accident. An example from another field is fatigue cracks in aircraft, which can be several decimetres before they reach their critical length. In this way they can be detected in one of the recurrent inspections in time to prevent an accident.

3.5 Reported accidents due to material failure

It is not easy to determine the frequency of incidents and accidents caused by material failure. There are several reasons for this. Firstly, the willingness to report incidents to authorities is very low. This is especially evident with near-accidents, i.e. when no one was hurt. Secondly, when reviewing the reports, the cause of the incident is often unknown. Sometimes the cause was not explicitly noted and sometimes it was unclear when the incident was reported.

Yet, the Swedish Consumer Agency has in their archive dozens of reports of incidents clearly due to material failure during the last two decades [47]. Perambulators/strollers are among the most represented. Only the last few years there have been several accidents in Sweden related to specifically the handle of perambulators/strollers. Handle breakage is more or less a new phenomenon which has increased as adjustable and reversible handles have become more common on the market. In some cases the handle has become completely disconnected. At other times the locking keeping a reversible handle in its place has fractured, allowing the seat to rotate, and resulting in accidents where the child hits the ground head first.
Another category with many reported incidents is swings. Here the material failure has occurred at different places; on one occasion one of the ropes broke, on another the crotch support came off and on yet another the attachment of the ropes broke. The common factor is that the broken parts were all made of polymers.

Without knowing many details of the swings in the reported accidents, one can guess why this category is very frequent among the accident reports. Swings are very exposed since they are situated outdoors, often all year round, enduring UV radiation, heat and cold, and their function is based on moving parts, grinding against each other.
4 Actions to minimize reduction of performance

4.1 Expected lifetime

As part of the safety assessment, the expected lifetime of a product must be defined. Many child articles are frequent on the second-hand market, for instance prams and strollers, high chairs, baby bouncers and reclined cradles. This must be considered in the assessment. Obviously the expected lifetime varies greatly between different categories of products and the procedure has to be repeated every time a new standard is being developed.

The European study ‘Child care and use products: inventory, risk assessment and safety requirements’[46] states that life time has to be taken into account for the preparation of a new standard to prevent potential hazards due to the ageing of the product. In the final report of that study 20 child care and use articles which need new or improved product standards are listed. Risk assessments are presented in individual reports for each product. However, there are only very few references to life and ageing in the individual reports. The main reason for this is probably the choice of products. The studied products are for indoor use, like high chairs and junior beds, or are not subjected to any significant load, like sun canopies and mosquito nets. No estimations of expected lifetimes are given for the studied products.

It is important to consider if a product is intended to be used outdoors, or, even if intended to be used only indoors, it is likely to be brought outside by the user. It should be kept in mind that the Product safety directive [1] and the Toy directive [2] require that foreseeable use shall be considered.

4.2 Testing and requirements – discussion

Different environmental factors will affect a material differently, but in almost all cases negatively. All plastics and other polymeric products are sensitive to sunlight and heat. Heat is always present and therefore plastics always have a limited lifetime. Resistance to those two factors is widely tested. However, material requirements concerning ageing and/or wear are not common among child articles or products similar to child articles. Existing tests and requirements on other products regarding these areas are discussed in this chapter. In Chapter 5 proposals for child articles will be presented.

In many industries requirements on materials can be extensive. The vehicle industry produces their own standard documents for material specifications. They code the materials for different environments and use requirement profiles for different applications. The applications decide environmental factors that will affect the material e.g. maximum occurring temperatures.

Requirements can be put on the material and/or the finished product. Equipment for personal safety is generally surrounded by many requirements. Helmets for personal protection at construction sites are, as a part of the CE-marking, always tested for the resistance to sunlight [13]. This is one example of product testing.

Many industries are more focused on the material used to produce the product. This is practical when you want to produce many different products of the same type for the same environment. Then you already know which materials to use and the product itself does not have to be tested. Specifications in the electronics industry are often focused on
material properties. An example of this is IEC 60079-0 ‘Explosive atmospheres – Part 0: equipment – General requirements’ [39], specifying materials used for housing of special categories of electric equipment.

The choice whether to evaluate the material or the finished construction is complicated. There are advantages and disadvantages to both approaches.

If the shaped product is evaluated, the mechanical test will be more realistic than for a material test specimen. It will however usually not generate any figure that can be compared with unaged parts. One will therefore not know how close the part was to failure. When evaluating ageing properties the material test is simply more informative, generating comparable figures.

When it comes to light exposure, things get more complicated. From which direction does the sun shine onto this specific part? If a shaped product is to be tested the orientation is very important since light simulation machines do not offer light from all directions. The directions of a material test specimen is much less complicated.

Another disadvantage of testing the shaped product is that the result will only be valid for the tested part. The producer has an economic advantage of evaluating the material and then produce many different parts from it.

When evaluating ageing properties of the finished part, the robustness of the construction is evaluated at the same time, which makes the test realistic. A material can have very bad light resistance but the product may not fail if the construction protects it. There may be load carrying parts that are perfectly shaded from light. The local thickness of the material can also save the part from failure from sunlight ageing.

There is another very important perspective: enforcement and market surveillance. In order to check conformity to legal provisions one must test the full product. Otherwise an authority will encounter difficulties to verify conformity to a standard (and regulation) because it will normally be difficult to get material test samples from the manufacturer and it may take a long time. Even if they send something it will be difficult to assess whether it is the same material as the one used in the product. Of course, once a certified material qualification is available it will be possible to check the certificates. But until then material testing may be good for internal quality control by the manufacturer but not necessarily the best option for a product specification/standard complementing European product safety legislation.

If testing of a full part can be practically and realistically carried out the test should be performed in that way. If not, it is better to evaluate the material.

When the ageing properties of a material are evaluated, a common technique is to evaluate the material by some kind of impact test. An impact test is easier to perform than e.g. a tensile test, which requires the shaping of a straight test specimen. An impact is also much more likely to actually cause the breakage of many plastic products in real life, including child products. There are of course exceptions to this.

Dropping a steel ball from a certain height is an easy way to perform an impact test and is still widely used. In addition there are many different kinds of impact testing machines which provide an impact strength graph from the test. The most established standard for this is ISO 179 ‘Plastics – Determination of Chary impact properties’ [33] and [34]. This method uses a hammer which swings and hits the test specimen which is put between two supports. Usually the energy needed to break the test specimen is recorded and used to calculate the impact strength, which is compensated for the dimensions of the specimen.
ISO 179 comprises two parts. Part 2 is for load cell instrumented machines, which are used to get more information out of the tests. The basic impact strength can be evaluated according to either part 1 or part 2.

An advantage of an impact test compared to other mechanical testing, is that the ageing degradation of a plastic often generates a relatively dramatic change in impact strength. Some plastics show their degradation by sustaining lower forces, others show lower ability to sustain deformation. As the impact strength is a mathematical integral of the force and deformation, it includes both cases.

If an ageing procedure corresponds to a realistic life time of e.g. eight years, a badly stabilized material will have dramatic change of impact strength after the exposure. Decreases of 50-90 % is common after a simulated life time. A decrease of 50 % can still be acceptable with normal safety margins of the construction, but more will be worrying. A well stabilized material usually shows a decrease of only 10-20 % in impact strength after a simulated life time.

There are cases when it is not logic to use impact testing for evaluation. A tensile test is preferable when the part is subjected only to tensile forces and a bending test should be used if the part is subjected only to bending. A soft material like rubber can not be evaluated by impact testing or bending, but must be evaluated by tensile testing. The rubber part may not be subjected to tensile forces, but the evaluation of ageing properties can practically seldom be evaluated in other ways. Measurement of hardness is common for rubbers but it is not very informative. A harder rubber is more an indication of bad mechanical properties rather than relevant for ageing.

Preferably the product can be age tested as it is, or it might be possible to take the product apart and age only the safety critical parts. If this is the case, the age test(s) can be performed before the mechanical tests, and should be regarded as preconditioning. That is, the result of the age test(s) is evaluated through the subsequent mechanical tests and not through explicit impact testing, as recommended in the study ‘Non-integrated finger protection – A background study and proposals of requirements and test methods’ [45]. It is important that the product or the detail is exposed to the light of such an orientation that the load carrying parts of the material really are hit by the light.

4.2.1 Light exposure – outdoor products

Products that are intended for outdoor use or which may be used outdoors should be tested for light resistance. Sunlight is in itself an effective energy to break a polymeric material. It also works as an initiation for further degradation by heat. In practice, all plastics for outdoor use must be protected by light stabilizers. Those can either block the light (UV-absorbers) or neutralize the aggressive chemical products produced by the light (e.g. antioxidants). The most important light stabilizer group is products based on hindered amines (HALS), which can be added in concentrations of 0.1 % to 3 % [50]. Those are expensive and the price of the plastic is highly dependent on the concentration of stabilizers. In practice, the most important reason to test the material or product is to make sure that the material is of the expected quality, since it might be tempting to cut down on the additives.

There are many different standards for testing resistance to sunlight. The most common methods are still based on outdoor exposures. Those methods are mainly for reference use. Most tests today are performed using artificial sunlight under accelerating conditions. This saves a lot of time. There are some established standards from the vehicle industry. The German vehicle organisation VDA (Verband der Automobilindustries) and the
American corresponding SAE (Society of Automotive Engineers) have published their own widely accepted standards in the field (e.g. SAE J1960 [40], SAE J2412 [41], VDA 75202 [43] and DIN 75220 [38] which was written by VDA). They are all techniques based on the xenon arc lamp.

The internationally most establish xenon arc standard is ISO 4892-2 ‘Plastics – Methods of exposure to artificial light – Part 2, Xenon-arc lamps’ [37]. More and more standards are referring to this international standard also in the vehicle industry. ISO 4892-2 includes two methods; method A for outdoor light and method B for indoor light. The lamp is filtered to, as closely as possible, generate the same spectral distribution as real sunlight. In method B the light is filtered with an extra window glass filter to simulate indoor light. This filter takes away most of the damaging UV light.

The standard also contains a number of different temperature and humidity cycles. The most widely used are Method A cycle 1 or 2 using constant light, 65 °C so called black standard temperature (temperature on a black surface insulated on the backside), 50 % relative humidity and water spray once every second hour. The cycle is very popular because it is generally usable with many weather elements and still has a good acceleration factor. Cycle 1 has an extra requirement of controlled 38 °C air temperature. Some older apparatus can not provide that.

In the car industry exposures according to ISO 4892-2 [37] of between 1000 and 3000 hours are common depending on where on a vehicle the component is situated. The technical requirements after such an exposure are generally quite tough. A typical requirement is maximum 20 % change in mechanical property.

The electronics industry also refers to ISO 4892-2 [37]. A typical requirement for housing material on an electrical apparatus is maximum 50 % decrease of impact strength after an exposure of 1000 hours to method A, cycle 1 [29] or [39]. The light dose of such an exposure is corresponding to about one year of constant outdoor use. This of course depends on the geographical location.

Testing according to ISO 4892-2 [37] is also common in the building materials industry. Around 2000-3000 hours exposure time is common for wall materials like paints, and 3000-5000 hours are common for roof materials. The requirement after such an exposure is typically maximum 20-30 % decrease in technical properties, like tensile strength or colour intensity.

Child articles generally have a shorter life than a car and definitely a shorter life than a building. For an expected life time of 5-10 years it may be suitable with a test exposure of 1000 hours according to ISO 4892-2, method A, cycle 1 or 2. At least safety critical parts should be able to stand such an exposure with a maximum of 20 % change in a suitable mechanical property.

4.2.2 Light exposure – indoor products

Products which are only used indoor may still be exposed to sunlight to such an extent that their characteristics are affected. This has historically mostly been a concern of the industries caring about esthetical properties, like the textile and car industries. Colorants for textiles, plastics and paints are sensitive to light even without the UV part. But even polymers are more or less sensitive to those wavelengths as well. The visible light is less harmful than the UV light, but not harmless.
The most established international standard for simulating indoor light is probably ISO 105-B02 ‘Textiles – Methods for exposure to artificial light’ [31]. The method has now been included in ISO 4892-2 [37] as Method B.

The exposure times are generally much shorter for indoor light. This is because of the fact that something inside a window never is exposed to direct sunlight for a whole day. The greater part of the sunlight is shaded away or reflected by the window. This gives the method a high acceleration factor compared to real circumstances. A typical exposure time is 200 to 400 hours. If mechanical properties are important there are longer exposures. Safety critical details in vehicles are tested for 1000-3000 hours, depending on where the component is mounted. The statement of the lengths of these exposure times is based on experience of technical requirement documents from Volvo, Scania, GM and VDA. These documents are generally not official.

Concerning the life time of a child article, a test exposure based on ISO 4892-2 method B for 500 hours, with quite tough requirements on mechanical properties of safety critical parts, may be suitable.

### 4.2.3 Heat exposure

The phrase that a plastic or rubber ‘has aged’ is commonly used. Most often this implies that heat together with oxygen has degraded the polymers into something chemically smaller or bigger, generating other mechanical properties, like brittleness or softness. Stabilizers are always added to the polymer to avoid this. The most commonly used, especially for rubber, is carbon black. But there are hundreds of different heat stabilizer products on the market. As mentioned before those products are generally expensive and in cheap products used only in small amounts.

All degradation of a polymer is chemical reactions, which always are temperature dependent. Most chemical reactions are accelerated by a higher temperature. Degrading reactions in polymers, mostly different oxidation reactions, can be fitted into the Arrhenius equation, which describes the temperature dependence of a chemical reaction, see below.

\[
k = A e^{\frac{E_a}{R T}}
\]

- \(k\) is the reaction rate constant (temperature dependent)
- \(A, E_a\) and \(R\) are constants
- \(T\) is the temperature

The equation can be more generally used to describe the degrading reactions as a group. Therefore much research has been carried out to find correlations between polymer degradation and temperature. As there are hundreds of different polymers and thousands of different additives for plastics production, it is impossible to investigate all those correlations. But it has been found that there is a usable rule of thumb. For every ten degrees Celsius above the normal use temperature of a product, the degrading reaction rate doubles. This is in practice widely used to make estimations of service life of materials and products. The materials are artificially aged at a higher temperature than the normal use temperature and evaluated by e.g. tensile testing or impact testing.

There are of course limitations in how much an ageing can be accelerated. There are critical temperatures for all materials where the properties change. The most obvious is the melting temperature, but even at lower temperatures there are softening changes in the material. If an accelerated ageing is carried out above those temperatures there will be
chemical reactions and rates of reactions that do not correlate with ageing in real use. Generally a lower acceleration during a material evaluation will correlate better with natural ageing. [50]

When it comes to techniques and equipment for accelerated ageing, some of the vehicle producers have their own standards. There are also some standards from the military and the electronics industry. But there is only one really established international standard; ISO 188 ‘Rubber, vulcanized or thermoplastic – Accelerated ageing and heat resistance tests’ [35]. The rubber industry was the first to write a standard and now it is very common by other industries to simply refer to this standard.

ISO 188 comprises two methods of heat ageing. The technical differences are the air speed and the fresh air change. The type 1 oven has a controlled slow and laminar air flow. The type 2 oven uses a fast turbulent air speed. Type 1 is mostly used in research. Type 2 is dominating for testing because of the less complicated equipment.

### 4.2.4 Fracture characteristics

If a product breaks it usually happens suddenly and unexpectedly. A product shall not break in such a way that the fracture itself can cause injuries. In the case of a child article it is especially important that the break itself is not the cause of any damages. When the product breaks, a sharp fracture edge can cause severe injuries. Nobody would design a child article made of glass for this reason, but the same kind of sharp edge fractures can occur by the breakage of other materials as well. If a material can break with sharp edges, the risk of injuries must be avoided by the design of the product. For instance, one should not be able to fall upon a sharp edge because of the failure.

When it comes to plastics this problem is mostly caused by additives like fillers or fibre reinforcements. Fillers are additives that generate a stiffer and also cheaper material. They are usually minerals, like clay or chalk. Those are very hard materials, which on a fracture edge can be cutting. As common as fillers are the reinforcement additives, like glass fibres or carbon fibres. A common example of the use of reinforcements is the use of carbon fibres in sports products. For instance, many floor ball sticks and tennis rackets contain carbon fibres. Reinforcement additives tend to cause even sharper edges than fillers. This behaviour can however be lessened, if not completely avoided, in the design of the material or product.

There is no general definition of ‘sharp’. The fracture will look very different from product to product and it can be hard to actually measure the sharpness. There are methods for this, but generally this has to be based on visual judgements. Also the risk of injury at breakage of the actual product or part of product has to be considered.

### 4.2.5 Wear – simulated use

Almost all products are subjected to mechanical wear when used. There might be friction between two moving parts of a product or between the product and something else, e.g. the user. Typical examples are all products which are possible to fold/unfold, take apart or adjust. These motions might, in time, significantly affect the performance of the product.

A wear test should simulate normal use. This is meant to be a preconditioning test, performed before assessing the safety of a certain function. The number of cycles for each motion should be based on the expected lifetime of the product, the frequency of use of
the product and the frequency of the motion when the product is being used. Since each
motion has a different frequency, this implies that the number of test cycles has to be
determined for each motion separately. Activating/deactivating the parking break of a
stroller is, for instance, a more frequent motion than folding/unfolding the stroller. Hence,
the wear test of the parking break should include more cycles than that of the folding
device.

As discussed in Chapter 2, wear testing is not included in hardly any existing child article
standards. There are however a few exceptions. The product standard for prams and
strollers [19], for instance, covers wear of the product to some extent through sequential
testing. The motions of normal use, such as activating/deactivating the parking break,
shall be performed 200 times before the safety of that function is to be tested. Another
example is baby carriers [26]. The durability of the attachment system of a baby carrier
shall be tested by placing the carrier on a test torso which then moves up and down,
simulating the user walking.

Requirements on furniture often includes wear testing. The difference here is that the tests
are mainly designed to determine the durability of the article. They are not intended as
pre-conditioning tests to be followed by mechanical and/or safety tests. As an example,
office work chairs are subjected to a total of 200,000 cycles of loading of different parts
of the seat. The backrest shall be loaded a total of 60,000 times, as well as the arm rests
[18]. Another example is testing of domestic beds and mattresses which includes a
durability test of the bed edge, in which a force of 1,000N is applied to the edge for 5,000
cycles by means of a loading pad [18]. To test the durability of a bed a roller applying a
load of 1,400N is rolled for a total of 30,000 cycles across the bed [22]. Functional
properties such as height, hardness and firmness are measured after the initial 100 cycles
and after the completion of the test. The changes in these properties are recorded.

Wear testing was included in the SP studies on finger protection [45] and child protective
products [49]. The studies of these reports recommend that normal frequent operations
shall be performed a number of times before testing of mechanical and safety qualities.
As an example, after ageing but before the mechanical tests, a child protective locking
device shall be subjected to two wear tests [49]. Firstly a force of 50N shall be applied
5,000 times to the device in its operating position, i.e. where it restricts further opening
of the window. Secondly the locking mechanism shall be engaged and disengaged 5,000
times. If it is possible, these tests shall be performed as one, where a load cycle includes
engaging of the device, opening of the window until the device is loaded as intended,
unloading of the device and disengaging of the device.

4.3 Material qualification systems

For plastic pipes and other products intended to have lifetimes of 50 to 100 years,
systems with qualifying of raw materials are used. The idea is to make an extensive initial
type testing of both the material and the product, including different long time ageing
tests (in some cases including up to 1 year testing time), and on the basis of these tests
certify the material for defined types of products. The future testing of the products will
then focus on a few key properties which show if the qualified material is properly
handled in the processing to the product. If the processing is OK the product is assumed
to have the properties demonstrated in the type tests.

This system puts a high demand on the type testing of the materials and restricts the use
of materials to those which have passed the qualification tests. On the other hand this
system will allow products to be produced to high standards with a high degree of
confidence on the basis of fairly simple product testing.
There are many kinds of material qualification systems. Another example is the electronic industry which has established standardised requirements on plastics for housing. The vehicle industry also has standardised material requirements, for instance Scania STD 3130 ‘Classification system for specifying plastic materials’ [42]. The requirements of those qualification systems may be suitable for child articles as well. In this kind of standards there is a list of about ten technical properties that are to be evaluated. The list also contains requirements. There are usually many requirement lists for different applications of the vehicle, but handling about 20 requirement lists is still more practical than specifying an exact material among thousands of products on the market.

If the requirements on a ‘qualified material’ for some other application are to be compared to the recommended requirements in this report, cf. Chapter 5, the technical conditions of the performed tests have to be compared in detail. If a performed test is a ‘worse scenario’, i.e. the temperature of the performed test is higher with (at least) the same exposure time as the recommendations, or the exposure time of the performed test is longer while the temperature is (at least) the same as in the recommendations, the test can be considered severe enough. There are of course more complicated situations, and calculations according to the Arrhenius equation may be used.

The construction plastics polyamides (PA) absorb water in relatively high amounts. This will affect the degradation chemistry. Therefore the humidity conditions during two different test methods are important when comparing. If two tests have been carried out under similar humidity conditions they may be comparable.

A material qualification system would make it easier for the manufacturers of child articles since they can refer to a complete system and do not have to specify each single requirement when dealing with their material suppliers. A qualification system would also make things easier for the material suppliers, especially if it is based on existing systems, since the material suppliers recognize the requirements and already know if a material meets the requirements or not.
5 Proposals of requirements and test methods

5.1 Age characteristics

Obviously the expected lifetime varies greatly between different categories of products and it is therefore impossible to suggest one criterion for all child articles. However, to simplify the proposals of this chapter, the requirements after heat ageing have been based on an expected lifetime of eight years. This is based on a product which can be used for/by two children in the same family and then sold on the second-hand market. Also, eight years was chosen as the expected lifetime of finger protection in the study ‘Non-integrated finger protection – A background study and proposals of requirements and test methods’ [45]. The proposed exposure times should be adjusted if the life of a product is intended to be significantly longer or shorter than eight years.

Since light exposure tests are very time consuming it is not justifiable to have an exposure time equivalent to the entire life time. Instead it is common practice to set a tougher requirement on the technical properties. Also, it is hard to assess exactly how much light a product is exposed to in real life. Not many articles will be exposed to sunlight all day long, all year round. Therefore experience is important when deciding on test parameters. The exposure times and requirements after light exposure recommended in this chapter are based on equivalent tests used in the vehicle industry.

5.1.1 Light exposure – outdoor products

If a child article is intended to be used outdoors, or if outdoor use is foreseeable, the plastic parts critical for the safety or function of the product, shall be tested for light resistance.

If possible, the product shall be aged as a whole. This shall be performed on the same sample as will be used in the heat exposure, safety and mechanical tests. The evaluation of the ageing shall be performed through the subsequent safety and mechanical tests. If it is possible to take apart the product, age the safety critical parts and then reassemble the product, this is also acceptable. If neither option is possible, the age test shall be performed on test samples which shall then be evaluated as follows.

The product (or test samples) shall be tested for outdoor light resistance accelerated under xenon arc light according to ISO 4892-2 ‘Plastics – Methods of exposure to laboratory light sources – Part 2: Xenon-arc lamps’ [37] for 1000 hours. The method of ISO 4892-2 shall be Method A cycle 2, specifying 65 °C black standard temperature, 50 %RH, and water spray 18 minutes every second hour. The xenon arc lamp shall be filtered with borosilicate filters for sunlight simulation and the irradiation shall be controlled at 0.51 W/m² at 340 nm.

If the product can not be tested and evaluated in whole or in part, the material is preferably tested as rods 80×10×4 mm where the flat 80×10 mm side faces the lamp. Theses specimens are for impact test evaluation.

The tested rods shall be able to withstand this exposure without losing more than 20 % of their impact strength, preferably measured according to ISO 179 [33] or [34]. Other methods of evaluation may be used according to Chapter 5.1.4 of this report.

Excepted from testing are parts of the product that are shielded from light by other parts. This includes light shielding by paints or other thick coatings.
5.1.2 Light exposure – indoor products

If a child article is to be used only indoors, the plastic parts critical for the safety or function of the product, shall be tested for indoor light resistance.

If possible, the product shall be aged as a whole. This shall be performed on the same sample as will be used in the heat exposure, safety and mechanical tests. The evaluation of the ageing shall be performed through the subsequent safety and mechanical tests. If it is possible to take apart the product, age the safety critical parts and then reassemble the product, this is also acceptable. If neither option is possible, the age test shall be performed on test samples which shall then be evaluated as follows.

The product (or test samples) shall be tested for indoor light resistance accelerated under xenon arc light, according to ISO 4892-2 ‘Plastics – Methods of exposure to laboratory light sources – Part 2: Xenon-arc lamps’ [37] for 500 hours. The test shall be carried out in the same way as described in Chapter 5.1.1 above, with exception of some machine parameters. The method of ISO 4892-2 shall be Method B, cycle 6, specifying 65 °C black standard temperature and 50 %RH. The xenon arc lamp shall be filtered with borosilicate and soda lime filters for simulation of sunlight through a window glass and the irradiation shall be controlled at 1.1 W/m² at 420 nm.

Test samples shall not lose more than 20 % of their impact strength, preferably measured according to ISO 179 [33] or [34]. Other methods of evaluation may be used according to Chapter 5.1.4 of this report.

Excepted from testing are parts of the product that are shielded from light by other parts. This includes light shielding by paints or other thick coatings.

5.1.3 Heat exposure

All child articles with polymeric parts critical for the safety or function of the product shall be aged through heat exposure. If possible, the product shall be aged as a whole. This shall be performed on the same sample as was used in the light resistance test, if any, and which will be used in the safety and mechanical tests. The evaluation of the ageing shall be performed through the subsequent safety and mechanical tests. If it is possible to take apart the product, age the safety critical parts and then reassemble the product, this is also acceptable. If neither option is possible, the age test shall be performed on test samples which shall then be evaluated as follows.

The product (or test samples) shall be tested for heat ageing resistance according to ISO 188 ‘Rubber, Vulcanized or thermoplastic – Accelerated ageing and heat resistance tests’ [35] at 75 °C for 90 days. An oven with forced turbulent air circulation shall be used (‘oven type 2’). The product or test samples to be tested are preferably hanged in the oven or put on a surface known not to influence the material at higher temperatures.

The test samples shall be able to withstand an exposure without losing more than 50 % of their impact strength, preferably measured according to ISO 179 [33] or [34]. Other methods of evaluation may be used according to Chapter 5.1.4.

It shall be noted that there is a material exception to this test method. The plastic ABS is a quite common construction material with good impact properties. It can not be evaluated by accelerated ageing since the ageing processes in the material at higher temperatures
will not correlate to real ageing. The evaluation of the durability of an ABS quality must be based on experience from practical use of reference products.

5.1.4 Alternative evaluation methods of age characteristics

The material characteristics of test samples shall be mechanically evaluated before and after an accelerated ageing. The method for evaluation shall be chosen based on the type of load the critical part is expected to be exposed to. Generally it is most common that a part will break from an impact. The material is then preferably evaluated by impact testing according to ISO 179 [33] or [34], as proposed in chapters 5.1.1 to 5.1.3.

The impact strength of a processed product can be evaluated by other methods, for instance by dropping a steel ball from different heights. The height required to break the product can be recalculated to an energy \( W = \text{mass} \times g \times \text{height} \) and compared before and after ageing. The requirement is still that the impact strength is allowed to drop by maximum 20 % after light ageing and maximum 50 % after heat ageing. A material test according to ISO 179 is still preferred.

If a detail is mainly tensile loaded, the complete part can be evaluated by tensile testing, and the maximum carried load is compared before and after ageing. A material can be tensile tested according to ISO 527 ‘Plastics - Determination of tensile properties’ [36] if it is a plastic or ISO 37 [30] ‘Rubber, vulcanized or thermoplastic – Determination of tensile stress-strain properties’ if it is a rubber. The tensile strength (maximum stress, MPa) and the strain (%) at maximum stress shall be compared before and after ageing. After a light resistance test those properties are allowed to drop by maximum 20 % and after heat ageing maximum 50 %.

A detail mainly carrying a bending load can be evaluated according to ISO 178 ‘Plastics – Determination of flexural properties’ [32] or ISO 527 ‘Rubber, vulcanized or thermoplastic – Determination of tensile stress-strain properties’ [36]. All mechanical testing is to be performed at 23 ±2 °C and 50 ±5 %RH after at least 16 hours conditioning in the same climate. The maximum recorded flexural stress and the flexural modulus shall be used for evaluation. After a light resistance test these properties are allowed to change by maximum 20 % and after heat ageing maximum 50 %.

5.2 Fracture characteristics

A product shall not break in such a way that the fracture itself can cause injuries. The fracture characteristics have to be evaluated manually; visually and by feeling, since there is no definition of ‘sharp’.

5.3 Wear – simulated use

All products which move in part or as a whole during normal use shall be tested for wear. This shall be a preconditioning test which shall be performed before assessing the safety of a certain function. The number of cycles for each motion shall be determined by taking into account the expected lifetime of the product, the frequency of use of the product and the frequency of the motion when the product is being used. Since each motion has a different frequency, this implies that the number of test cycles has to be determined for each motion separately. Also, it is important to include a safety factor.
5.4 Material qualification system

In addition to the recommendations contained in this study the authors suggest to consider the establishment of a material qualification system based on existing systems from other industries.
6 Conclusions

The life of a product varies greatly with the environment. It is clear that the material and processing have to be chosen based on the knowledge of the environment in which the product will be used as well as the expected lifetime. Environmental engineering can be a useful tool in this process.

In order to simplify the material selection process when a product is developed, it is recommended to compose a material qualification system for child articles. This system can preferably be based on existing systems from other industries. It is also recommended to perform a subsequent study to evaluate the conformity between impact strength testing of aged material samples and reality based mechanical testing of aged complete products.

This study recommends that the requirements and test methods proposed in Chapter 5 are considered when new standards for child articles are being developed or when existing standards are being revised. It is also recommended to perform a risk analysis to identify the hazards of a product.
7 References

European directives


European standards


[29] EN 60079-0:2006 Electrical apparatus for explosive gas atmospheres – Part 0: General requirements, 2006

**International standards**


**Other standards**

[38] DIN 75220 Ageing of automotive components in solar simulation units, 1992.
Other references


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