



**Construction  
Focus Report 2010  
Adhesive & Sealants**

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## 1. Executive Summary

The objective of this report is to analyse the evolution of nanotechnology in the development of adhesives and sealants for the construction industry.

Adhesives and sealants are used in many industries to join or bond similar or different materials. Adhesives and sealants are based on the same chemistry but differ in their functionality. The main difference between adhesives and sealants is the modulus of elasticity; a sealant has a lower strength. Within the construction industry adhesives and sealants are used in applications as varied as carpet laying, ceramic tiling, concrete, countertop lamination, flooring underlay, drywall lamination, heating, ventilation, air conditioning, joint cements, manufactured housing, pre-finished panels, resilient flooring, roofing, and wall coverings, amongst others.

Today, nanotechnology is present in the adhesives and sealant industry in the form of nanoscale fillers such as fumed silica, nano precipitated calcium carbonate, and titanium dioxide. Fillers have been traditionally used in adhesives and sealants formulations with the objective of cheapening the product; however, the situation has changed nowadays, as nanoscale fillers are providing adhesives and sealants with improved performance and additional functionalities including superior physical properties, rheological control, flame resistance, and improved durability and recyclability, amongst others.

The main fillers used in the production of adhesives and sealants, which utilise nanotechnology today, are fumed silica, nano PCC, and to a lesser extent, TiO<sub>2</sub>. Fumed silica, also known as pyrogenic silica, can be produced with a particle size of several 10nm and a specific surface area of 90m<sup>2</sup>/g to 600m<sup>2</sup>/g. Fumed silica can be produced through a hydrolysis process or through precipitation process. As its name indicates, the production process of NPCC involves precipitation, which yields a particle size in the range of 60-150nm. These nanoproducts have been available in the market for several years now, serving a wide array of industries such as paper, cosmetics, food, plastics, and adhesives and sealants.

In Europe, the construction industry represents the second largest market for adhesives and sealants. It is estimated that the size of the adhesives and sealants market of products that are directly related to the construction industry in Europe was close to €1,9 billion in 2009. However, only a few products in this market are nanotechnology-enhanced. It is estimated that only 10% of all adhesives and sealants contain nano fillers and in very low percentages. There are several drivers and barriers that affect the adoption of nanotech-enhanced adhesives and sealants in the construction industry. The main drivers include improved performance, additional functionalities, and environment-related features, while the main barriers are price competitiveness, lack of awareness and risk avoidance.

It is perceived that nanotechnology will contribute to the development of a new generation of adhesives and sealants in the coming years, and that the market will continue growing. However, it is necessary to ensure that these developments go together with appropriate regulation in aspects such as health and safety, and that both the benefits and concerns about these products are extensively communicated and discussed across the value chain, from the nanoscale filler producer, through the adhesives and sealants producer, to the construction

industry. This will not only help to lower the barriers of technology adoption, but also contribute to new developments in this field.

## 2. Introduction

### 2.1 Definition

Adhesives and sealants are formulated products for joining or bonding different or similar materials. Adhesives and sealants are based on the same chemistry but differ in their functionality. Adhesives are used to bond similar or different materials together, whereas sealants create an impermeable and mostly flexible barrier preventing the passage of water and air. Sealants fill in the gap between building joints and provide a barrier function (joint sealant). The typical difference between adhesives and sealants can be found in the modulus of elasticity, that is a typical sealant has a lower strength. Common sealants are based on curable elastomers containing a filler material. However, the fixation functionality of an adhesive can also be formulated into sealants, and an adhesive may also have the barrier functionality from traditional sealants. Important material classes are silanes, urethanes, acrylics and epoxies, amongst others. Adhesives can be based on “physical hardening”, for example hot melts or solvent-based adhesives, or on “chemical curing”, whereby a chemical reaction is responsible for the hardening process. Adhesives and sealants can be based either on one or on two components.

According to the Association of European adhesives and sealants manufacturers and their national trade associations (FEICA), adhesive and sealant products can be classified as follows<sup>1</sup>:

**Adhesive Products:**

- Adhesives based on natural polymers
- Polymer dispersion/emulsion adhesives
- Hot melt adhesives
- Solvent based adhesives
- Reactive adhesive systems
- Adhesives based on water-soluble systems
- Others

**Sealant Products:**

- Oil-based caulks
- Acrylics (water and solvent based)
- Polyvinyl acetate caulks
- Butyls
- Polysulphides
- Polyurethanes
- Silicones
- Silane modified polymers
- Others

#### Fillers

Fillers are materials used to reduce the volume formulation costs, that is to reduce the cost of a material by lowering the use of expensive binder. Fillers are widely used in sealants but also

<sup>1</sup> “The European Adhesives and Sealants Market 2007-2010”, A quantitative demand analysis and trend forecast, FEICA, CHEM Research GmbH, 2008

in adhesives. Important filler materials are calcium carbonate and silica, whereby the former one is the most widely used filler materials today.

#### Rheology Modifier

Traditional rheology modifiers are used as thickening agents to increase the viscosity. They are widely used in coatings but also in adhesives and sealants. Fillers also influence the rheological properties, but this property is strongly pronounced when moving to the nanoscale. High performance “fillers” are also called rheology modifiers. They influence the viscosity, the shear viscosity, and thixotropy<sup>2</sup>, and are also used to tune the modulus of elasticity.

#### Coupling Agents

Coupling agents are used to bind inorganic fillers or reinforcement material to the polymer matrix in a composite material. Coupling agents improve the mixing (dispersion) and increase the matrix strength. Coupling agents are used as additives in adhesive and sealant formulations.

## 2.2 Keywords

Sealants, adhesives, additive, binder, filler, weatherability, sealed joint, adhesive fixation, smart curing, disbond-on-command, plasticizers, stabilizers, thixotropy, viscosity, rheology, rheology modifier, rheological control, modulus, cracking, cracking behaviour, silica, fumed silica, silica fume, precipitated silica, SiO<sub>2</sub>, magnetite, Fe<sub>3</sub>O<sub>4</sub>, ground calcium carbonate, GCC, precipitated calcium carbonate, PCC, nano precipitated calcium carbonate, NPCC, CaCO<sub>3</sub>, silanes, titanates, zirconates, coupling agent, structural glazing, curtain walls, structural glazing adhesive.

## 2.3 Overview

Adhesive and sealant formulations are based on a huge variety of natural or synthetic materials. To establish durable bonds and sealed joints between numerous materials such as wood, metal, glass and ceramics is a rather challenging task. The basis for adhesives and sealants is polymer chemistry with certain additives and fillers to improve their characteristics. In addition, curing technologies, adhesive application technologies, and substrate preparation techniques are important.

Although traditional formulations are based on polymer chemistry (for example synthetic resin and rubber elastomers), nanotechnological approaches are gaining importance in adhesives and sealants.

Fillers have been used for a long time to reduce the product cost by adding a reasonable amount of a low cost material. Today, the situation has changed and fillers have begun to influence the rheological properties. The reason can be found in the improved production techniques that have made the fabrication of smaller particles with narrow size distribution and different chemical coatings possible. Today even nanoscale fillers with tailored surface chemistry are on the market allowing true rheological control with improved mechanics.

Virtually every natural mineral can be used as a filler material. Important product groups are paper, plastics, rubber, paints, adhesives and sealants. Important filler materials are ground calcium carbonate, precipitated calcium carbonate, carbon black, kaolinite and feldspar. Silica

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<sup>2</sup> A thixotropic fluid becomes less viscous when stirred or shaken

or fumed silica is also gaining importance for many different applications. It is sometimes referred to as “white carbon black” because it can be used to replace carbon black fillers in rubber products, and to improve material strength.

Major fillers in adhesives and sealants are ground calcium carbonate, precipitated calcium carbonate and fumed silica. The latter two are important with respect to nanotechnology. They can be produced with a controlled particle size down to the nanometre scale.

Smart adhesives that allow “disbond-on-command” are also widely discussed in relation to nanotechnology. Magnetite nanoparticles mixed with the adhesive formulation could enable the disassembly at the push of a button. A selective disassembly of components will become more and more important in the future, especially with respect to the recycling of materials, a critical issue for a sustainable development. Generally, the use of environmentally friendly materials such as biopolymers will have an increasing impact in future research and development. In this respect, also the dream of switchable adhesives exploiting smart curing technologies may become true. True switchable bonds can be found in nature. The feet of geckos adhere on almost every surface. The “setae” on the toes of a gecko are using van-der-Waals interactions to establish a fully reversible attachment. A synthetic gecko foot would enable a new generation of adhesive products.

## 2.4 Methodology

This report has been compiled by desk research and expert consultation.

# 3. Scientific and Technological Aspects

## 3.1 State of R&D

A major concern towards sustainable construction is the development of green adhesives and sealants with environmentally friendly properties. In this sense, the removal of organic solvents and the reduction of volatile organic compounds (VOC) have been investigated intensively in recent years. Although water-based adhesives were introduced in the 1980s, there are still a number of solvent-based adhesives today that cannot be replaced by their environmentally friendly counterparts<sup>3</sup>.

The use of biopolymers made from microbial processes could especially revolutionize future construction materials and adhesives. Adhesives based on natural glues such as starch, have also been a topic of intensive research<sup>4</sup>.

A key element in current research is the durability of sealed joints and adhesive fixations. Especially when used outdoors, adhesive and sealant’s weatherability is a critical issue; expanded weatherability can be achieved by optimizing the chemical composition. The influence on the weathering behaviour of sealants utilizing different binders, plasticizers, stabilizers and fillers has been investigated<sup>5</sup>. Here the cracking behaviour of the sealant surface

<sup>3</sup> “Considerable further potential for adhesives” <http://www.hiwaconsul.de/pdf/stick.pdf>

<sup>4</sup> Market Report “The Future of Green Adhesives and Sealants for Industrial Applications - Market Forecasts to 2017”, Pira International 2009

<sup>5</sup> Claus Urban, Tsuyoshi Matsumoto, Shogo Tomari, Francois Adeleu, Journal of ASTM International, Vol 4, No.1, in “Durability of Building and Construction Sealants and Adhesives”, 2nd Volume

is an important issue<sup>6</sup>. It is expected that high performance sealants using more expensive raw materials will replace today's standard grade sealants in the near future. In this respect, increased service-life is desired. The durability of sealants that undergo movement is strongly dependant on the modulus. Typical applications for sealants with high joint movement are curtain walls, highway pavement joints, parking decks and bridges. A lower modulus will lead to an increased durability. In this regard, a sufficient substrate adhesion of the sealant is a critical issue. It has been shown that the modulus can be reduced by adding suitable chemicals without lowering the substrate adhesion<sup>7</sup>.

A major field of research can be found in the traditional polymer chemistry, where polyurethanes and silanes play a dominant role. Furthermore, a fast curing process is of great interest. Traditional approaches rely on heating or UV irradiation. An extremely fast curing process can be achieved by laser or microwave technologies. These so-called smart curing technologies can also benefit from nanomaterials. Superparamagnetic nanoparticles such as magnetite ( $\text{Fe}_3\text{O}_4$ ) can be dispersed in adhesive formulations. In a second step, an external electro-magnetic field or microwaves can be used to introduce energy<sup>8</sup>. The nanoparticles are forced to oscillate, which leads to a heat transfer into the surrounding matrix by friction losses. This method can also be transferred to an excitation by sole electrical fields in combination with piezoelectric nanoparticles or magnetic fields with ferromagnetic particles. This method could also be extended to a disbond-on-command functionality.

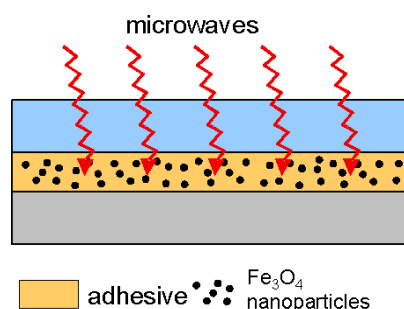


Figure 1: Disbond-on-command: Well dispersed superparamagnetic nanoparticles oscillate in an external electro-magnetic field. Heat is generated due to friction losses.

The idea of a switchable adhesion can also be addressed by selecting suitable materials and sophisticated techniques<sup>9</sup>. A true switchable and reversible adhesion can be found in nature: geckos and insects can climb up walls and even walk on ceilings. However, there is no such adhesive product on the market today. Another challenge for future research and development is the wettability of low energy surfaces<sup>10</sup>.

The major impact of nanotechnology on adhesives and sealants can be found in nanoscale filler materials. Traditional fillers are used to cheapen the material and have no impact on the

<sup>6</sup> A.T. Wolf, Shigeki Sugiyama, F. Lee, Use of Optical Imaging/Image Analysis System for the Quantitative Analysis of Surface Changes Induced by Outdoor Weathering on Sealants, Journal of ASTM International, Vol 3, No.6, in "Durability of Building and Construction Sealants and Adhesives", 2nd Volume

<sup>7</sup> Reducing Modulus of Sealants to Improve Durability, J.M. Klosowski, J. E. Plott, Journal of ASTM International, Vol 3, No.4, in "Durability of Building and Construction Sealants and Adhesives", 2nd Volume

<sup>8</sup> US Patent 7147742 - Method for accelerating the curing of adhesives,

<http://www.patentstorm.us/patents/7147742/description.html>

<sup>9</sup> "Controlling Network-Brush Interactions to Achieve Switchable Adhesion", Rita La Spina, Michael R Tomlinson, Lorena Ruiz-Pérez, Arnaud Chiche, Sean Langridge, Mark Geoghegan, Angewandte Chemie International Edition, Volume 46 Issue 34, Pages 6460 - 6463

<sup>10</sup> "The Future of Adhesives and Sealants seen from a European Perspective", Juergen Wegener, the ChemQuest Group; Inc., 2004.

rheological properties. In contrast, nanoscopic fillers allow rheological control and lead to improved mechanics, for example they act as reinforcement. The most important filler materials are calcium carbonate and silica. For this reason they are treated separately in the following lines. Both nanomaterials are already commercially available. Titanium dioxide is also under investigation as a filler material in adhesives and sealants<sup>11</sup>. It may also serve as a thickening agent. However, it is used to a lesser extent than calcium carbonate and silica. For this reason it is not analysed separately in the following paragraphs.

To enable a comparable evaluation of nanotechnology related applications, the following "Technology readiness Levels" (TRL) have been defined for scientific or technological evaluations within ObservatoryNANO reports:

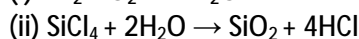
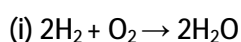
- TRL 1: "basic research"
- TRL 2: "applied research"
- TRL 3: "prototype / lab device"
- TRL 4: "market entry"
- TRL 5: "mature market" (mass- or established niche markets)

The TRLs will be used to classify specific applications according to their technological readiness.

### 3.1.1 Fumed Silica (TRL 2-5)

Fumed silica is a white fine-grained powder of non-crystalline silicon dioxide. Fumed silica is widely used as a thickening agent in the food and cosmetic industry. It is also used as filler in coatings, plastics, adhesives and sealants. Fumed silica is often mixed up with silica fume, which is an industrial by-product of silicon production. Silica fume or micro-silica is used in cements serving as a pozzolan that supports the cementitious reaction. Although being chemically very similar, fumed silica is much finer than silica fume<sup>12</sup>.

Converting gaseous silicon tetrachloride into SiO<sub>2</sub>, in a flame hydrolysis process, produces fumed silica:



Fumed silica is sometimes also referred to as pyrogenic silica. An alternative production method of pyrogenic silica is the use of an electric arc. Fumed silica has a specific surface area of 90m<sup>2</sup>/g to 600m<sup>2</sup>/g<sup>13</sup>. The flame hydrolysis process allows the production of homogeneous silica particles with narrow size distribution and tunable specific surface area. Although the primary particle size is about several 10nm, larger agglomerates are usually formed. Untreated grades of fumed silica are hydrophilic. Hydrophobic grades are produced using silanes or siloxanes to bind on the particle surface.

Fumed silica can be added to powders to ensure free flow and to prevent caking. In liquids it serves as thickening agent with thixotropic property. A thixotropic liquid becomes less viscous

<sup>11</sup> "Study of the adhesive strength of Thiokol-based sealant-metal joints", <http://www.springerlink.com/content/r78344448368v275/>

<sup>12</sup> Fumed silica could also serve as Pozzolan in cement based material. However, it is more expensive than silica fume which prevents a broader use in high performance concretes so far.

<sup>13</sup> European Patent EP0759410, <http://www.freepatentsonline.com/EP0759410.html>

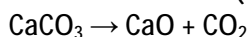
when an external force is applied, that is by stirring, and it will settle quickly after the external force is removed.

Another production process is based on precipitation. Precipitated silica consists of nanoscale primary particles that agglomerate into larger clusters with a size of several micrometers. In contrast to fumed silica, precipitated silica consists of porous particles. Precipitated silica is also used for example as filler material in elastomers.

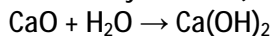
### 3.1.2 Precipitated Calcium Carbonate (PPC), (TRL 2-5)

Carbonate minerals are the second most abundant minerals in the earth's crust after silicates. For this reason they are also widely used as a cheap filler material. Calcium carbonate ( $\text{CaCO}_3$ ) is the most common carbonate mineral and the most widely used filler material today. It naturally occurs in three polymorphisms called calcite, aragonite and vaterite. Limestone, chalk and marble are the most common naturally occurring calcite sources on earth. They can be crushed easily and processed by milling techniques into a fine-grain powder. The resulting material is referred to as ground calcium carbonate (GCC), which is widely used as filler material especially in the paper industry. The global production capacity of ground calcium carbonate is steadily growing and has reached 73 million tonnes in 2008<sup>14</sup>. It is available in many different grades, differing in particles sizes and chemical purity (colour). Ultra-fine GCC has particles sizes within several micrometers. The distribution of particles sizes however is fairly large due to the mechanical production technique. Therefore, GCC is a suitable, cost efficient filler material, but its ability to modify the rheological properties is rather limited.

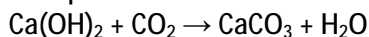
An alternative production process of calcium carbonate that allows the production of a narrower particle size distribution is the precipitation technique or recarbonisation method. The resulting synthetic filler material is referred to as precipitated calcium carbonate (PCC). The PCC production is based on the same raw material as the GCC production. The control of particle size is obtained through a controlled precipitation process from slaked lime. The size of the  $\text{CaCO}_3$  particles can be tuned by adjusting the time of reaction, the temperature and the concentration of reactants. A common production process is based on the decomposition of calcium carbonate (i.e. from limestone) at high temperatures in a kiln (calcination):



Calcium hydroxide (slaked lime) is formed by adding water:



Precipitation occurs when carbon dioxide is passing through (recarbonisation):



The resulting slurry can be used as it is or transformed into a solid. In the latter case the slurry is filtered and disagglomerated by mechanical means, i.e. grinding or milling techniques. The initial production process is similar to that of ordinary Portland cement.

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<sup>14</sup> The Economics of Ground Calcium Carbonate, 3rd edition 2008, <http://www.roskill.com/reports/ground>



Figure 2: Images of different grades of calcium carbonate. Left: Calcium carbonate (Wikipedia.org), Right: Nano precipitated calcium carbonate, (Shandong Haize Nano Material Co. Ltd, China)

Depending on the specific use, treated and untreated grades of PCC are available. Treated grades are normally reacted with fatty acids, such as stearic acid, for the use in non-aqueous environments. Fine and ultra-fine grades of PCC are sometimes called nano precipitated calcium carbonate (NPCC). Average particle size of NPCC ranges from 60-150nm. Fine and ultrafine PCC is used as advanced fillers in sealants to control rheological properties such as viscosity, sagging or slump. It is also used in plastics, for example window frames, to increase their stiffness, impact resistance and weatherability.

### 3.1.3 Coupling Agents (TRL 1-5)

Coupling agents are reactive chemical compounds that bind the filler material to the surrounding polymer matrix. Coupling agents increase the overall matrix strength and improve the dispersion of the filler material. Common coupling agents are based on silanes. More recently, also titanates and zirconates have shown to work as effective coupling agents. Coupling agents are very similar to so called "adhesion promoters"<sup>15</sup>, which are used to enhance the adhesion of surfaces. Adhesion promoters are either applied directly to the surface or mixed with adhesive formulation. An improved mixing of the filler material ("dispersion") is an important property, especially with respect to nanomaterials that tend to agglomerate into larger clusters.

## 3.2 Additional Demand for Research

A key issue for high performance adhesives and sealants is their durability and weatherability in the case of outdoor use. In this regard, mechanical stress due to wind loads, dead loads or thermal expansion is a matter of future research. In addition, safety and security aspects have to be considered, such as earthquakes, fires and bomb blasts. Here, high performance structural silicone sealants have proven to significantly increase the protection of residents<sup>16</sup>.

<sup>15</sup> "Adhesion promotion on inorganic and organic substrates", Adhesivemag.com, <http://www.oxfordsurfaces.com/pdf/press/OAS-jan-2010.pdf>

<sup>16</sup> Dow, Corning, Structural Silicone Glazing, [http://www.dowcorning.com/content/publishedlit/qb\\_silicone\\_structural\\_glazing-the\\_art\\_of\\_the\\_possible.pdf](http://www.dowcorning.com/content/publishedlit/qb_silicone_structural_glazing-the_art_of_the_possible.pdf)

The wettability of surfaces is another important field of future nanotechnology research that has an enormous impact on the durability of adhesive fixations and sealed joints.

In general, nanomaterials are believed to enable novel adhesives and sealants with unsurpassed properties. This can only be achieved by an improved dispersion of nanomaterials in polymer matrices. This is still a key challenge for future research and development not only restricted to the construction sector. Gaining better control in the “mixing” of nanocomposites will pave the road towards an improved mechanics and rheological control. In this sense, coupling agents and adhesion promoters with enhanced properties are of great importance.

Key issues:

Durability / weatherability  
Wettability of surfaces  
Dispersion of nanoparticles

### 3.3 Applications and Perspectives

Fields of applications within the construction sector are building construction, civil engineering and glazing. The construction sector is the second largest market of adhesives and sealants within the EU. Application possibilities within the field of building are numerous. Adhesives and sealants are used for carpet laying, ceramic tiling, concrete, countertop lamination, flooring underlay, drywall lamination, heating, ventilation, air conditioning, joint cements, manufactured housing, pre-finished panels, resilient flooring, roofing and wall covering, amongst others<sup>17</sup>.

Important fields of application in civil engineering are joint sealings for pavements and bridges amongst many others.

High performance adhesives and sealants are used for glazing. Over the past decades urban skylines have changed dramatically due to a change in the construction materials. Steel and glass have been increasingly used to construct almost seamless facades. The use of so-called curtain walls has given architects new possibilities for the design of buildings. Structural glazing is a highly versatile form of curtain wall construction. Here, the glass is attached by silicone adhesives to the structure of the building, for example the curtain wall frame. Static loads, such as wind loads, are transferred through structural silicon sealants to the underlying structure of the building.

<sup>17</sup> Market segments according to FEICA [http://www.feica.com/index.php?option=com\\_content&view=article&id=32&Itemid=55](http://www.feica.com/index.php?option=com_content&view=article&id=32&Itemid=55)

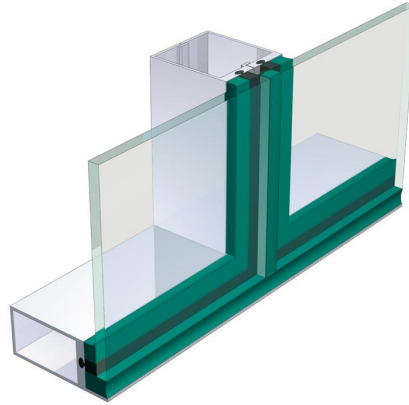


Figure 3: Structural Glazing - Window panes are fixed by a structural silicone sealant. Source: Tremco illbruck GmbH & Co. KG

For this reason it is also called structural silicon glazing and the sealant is referred to as structural silicone. Silicone is used for structural glazing because of its outstanding durability and weatherability. Nevertheless, the structural silicone sealant will suffer from shearing stress due to thermal expansion and wind loads<sup>18</sup>. In this sense, high performance sealants with known fatigue characteristics are needed to prevent degradation or failure within the lifetime of the building.

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<sup>18</sup> "Development of a Practical Method to Evaluate the Fatigue Properties of Structural Silicone Glazing Adhesives", L.D. Carbary, E.D. Bull, S.S. Mishra, Journal of ASTM International, Vol 4, No.1, in "Durability of Building and Construction Sealants and Adhesives", 2nd Volume

### 3.4 Current Situation within the EU

Adhesives and sealants are widely used in many different industrial sectors. The demand for adhesives and sealants has steadily grown. Major producers and consumers are the United States, Japan, Germany, Italy, United Kingdom and France. The region with the highest growth however is the Far East, especially China<sup>19</sup>.

The demand for adhesives and sealants within the EU27 reached 3.2 Mill. tonnes in 2008<sup>20</sup>.

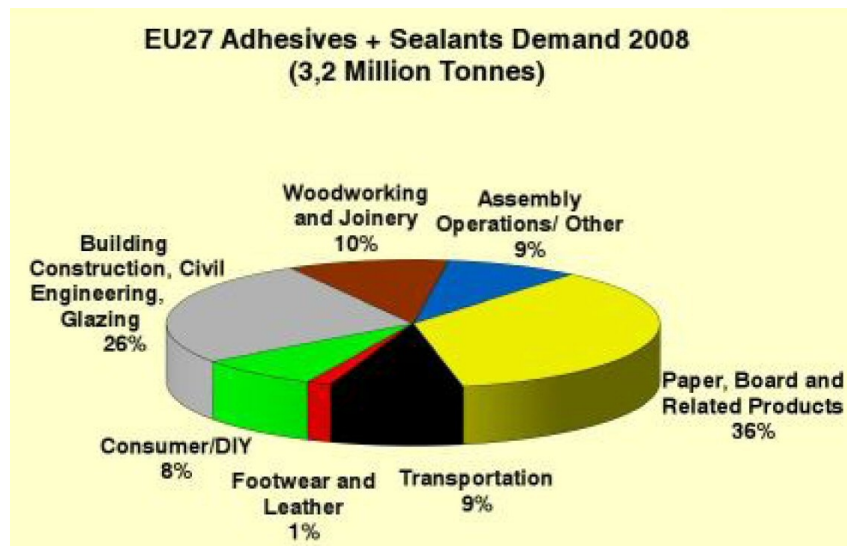


Fig 4: Segmentation of market of adhesives in sealants within the EU27, FEICA 2008 (Association of European adhesives and sealants manufacturers and their national trade associations)

The global demand for fillers is also steadily increasing. More than 50 Million tonnes have been used in 2006 (25 Bill. Euros) and the average annual growth rate is about 3%<sup>21</sup>. Fillers are one of the most considerable resources in the world. Today's major markets North America and Europe are shifting towards Asia, especially China and India.

### 3.5 Links

FEICA: (Fédération Européenne des Industries de Colles et Adhésifs) is the Association of European adhesives and sealants manufacturers and their national trade associations, <http://www.feica.com/>

German Adhesives Association - Industrieverband Klebstoffe e.V. (IVK) <http://www.klebstoffe.com/>

British Adhesives and Sealants Association. BASA is the trade body representing the interests of adhesives and sealants manufacturers in the UK and Ireland. <http://www.basa.uk.com/>

<sup>19</sup> "Adhesives & Sealants/Joining and Fastening", BBC Research 2007 <http://www.bccresearch.com/report/CHM048A.html>

<sup>20</sup> "Adhesives and Sealants Demand in Europe in 2008", FEICA [http://www.feica.eu/index.php?option=com\\_content&view=article&id=28&Itemid=52](http://www.feica.eu/index.php?option=com_content&view=article&id=28&Itemid=52)

<sup>21</sup> Market Report "Fillers" (Marktstudie Füllstoffe (UC-805)), Ceresana Research, 2007.

Adhesive and Sealant Council (ASC) is a North American trade association dedicated to representing the adhesive and sealant industry.

<http://www.ascouncil.org/>

Adhesives.org is an online educational portal providing unbiased information about adhesives and sealants to those that are relatively unfamiliar with the technology. <http://www.adhesives.org/>

The Adhesion Society

Organization of scientists and others dedicated to scientific and technical issues related to the science and technology of adhesion. Aim: Promote the advancement of the science and technology of adhesion and the dissemination of this knowledge.

<http://www.adhesionsociety.org/>