FORMALDEHYDE FREE COMPOSITE WOOD PRODUCTS FOR IMPROVED INDOOR AIR QUALITY

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ABSTRACT

Formaldehyde, a major indoor pollutant, originates mainly from the formaldehyde resins, which are used in the production of composite wood panels (e.g. particleboard, fibreboard, plywood) employed in furniture and building construction. To avoid health effects, national regulations have been established, restricting the levels of formaldehyde emission from composite panel products as well as the formaldehyde indoor levels. These levels have been continuously reduced over the past years. To protect consumer health and help satisfy the acceptable formaldehyde levels, CHIMAR HELLAS has developed novel adhesive resin technologies, which provide composite panels with emission at the level of natural wood, while simultaneously maintaining acceptable bonding performance.

1. INTRODUCTION

The composite wood-based panels, whose main representatives are products like the particleboards, medium density fibreboards (MDF), plywood and oriented strand boards (OSB), constitute the main materials for the production of furniture as well as for interior house construction (e.g. flooring, wall panelling). In addition, in some countries like the USA, Canada and the Scandinavian countries these products are used in exterior applications as well. (e.g. roofs, prefabricated houses).

Wood-based panels are produced from wood particles, fibres, strands or veneers, which are bonded together via thermosetting resins based on formaldehyde. These resins result from the condensation polymerisation of the following monomers (Picture 1):

1) Formaldehyde (F)
2) Urea (U) and
3) Melamine (M).

They are chemically known as aminoplastic resins, with most important family member the urea-formaldehyde resins (UF). The latter combine the advantages of high reactivity, optimum performance in board production and low cost. Approximately 15 million tones of formaldehyde resins (in liquid form) are employed worldwide per year[1]. In Europe, the corresponding quantity approaches the 6 million tones, 80% of which are for UF resins.

The susceptibility of UF resins to hydrolysis renders them more effective in interior grade panels and together with the presence of free non-reacted formaldehyde contributes to the problem of formaldehyde emission from the panel products both during manufacture and service. In the latter case, the formaldehyde emission persists for a long time, due to the ongoing hydrolysis of the resin. Nevertheless, part of the emissions derives from wood itself, as formaldehyde is one of its natural components. Concisely, the formaldehyde emission from wood-based products is influenced both from endogenous and exogenous factors and more specifically by the following:

INTRINSIC FACTORS

- Type of wood

- Type of bonding resin
- Board production conditions
- Product age

EXTERNAL FACTORS

- Room temperature and relative humidity
- Room ventilation rate
- Overall board surface at given room space

Indoor air quality and formaldehyde emissions from composite wood products first became subject to broad public and governmental concern in the late 1970s, when the energy crisis encouraged heat conservation through tight sealing of homes. This reduced the rate of outdoor air infiltration and overall ventilation rates leading to the entrapment of gaseous pollutants inside home air atmosphere. With Europe and North America as pioneers, test methods to accurately measure formaldehyde emissions from panels were developed and product emission guidelines were established. A total change in the formulation of UF resins was made by the resin industries to meet these low emission guidelines. Moreover, competitive bonding systems such as phenol-formaldehyde resins or polymeric diphenyl methane diisocyanate (PMDI) binders were proposed.

2. FORMALDEHYDE HEALTH EFFECTS

Formaldehyde is a naturally occurring substance, which is widely met both in humans and plants. It is also used in the production of other chemical products and materials (i.e. dyes, fabrics, medicines). Indoors, formaldehyde can be emitted apart from the furniture that contain composite wood products, by varnishes, insulating materials, wallpapers, paints etc. Formaldehyde is also present in combustion gases and even in cigarette smoke.

Formaldehyde is a colourless, but strong-smelling gas and thus can be easily detected and the exposure to high formaldehyde concentration can be avoided. When present in the air at levels above 0.1 ppm, it can cause watery eyes, burning sensations in the eyes, nose and throat, nausea, coughing, chest tightness, wheezing and headache. It can affect people differently; some people are very sensitive to formaldehyde while others may not have any noticeable reaction to the same level. Most of these symptoms disappear via exposure in clean air. Some people may also present skin rashes, and allergic reactions. It is pointed out that formaldehyde is neither accumulated in the environment nor in the human organism because it is quickly oxidised and biodegraded.

It is argued that there are more severe effects at long-term exposure. Scientific studies in the early 1980s have demonstrated that formaldehyde is a strong nasal carcinogen in rodents exposed in high formaldehyde concentrations and this has led to concerns about the potential for carcinogenic risk to humans. Up to recently, formaldehyde was classified as a "probable" human carcinogen (category 2A) by the International Agency for Research on Cancer (IARC), under the auspices of the World Health Organisation (WHO). In June 2004, IARC decided to reclassify formaldehyde to "known" human carcinogens. However, the IARC evaluation was based on studies evidencing limited carcinogenicity in industrial workers exposed to high formaldehyde concentrations 30 to 60 years ago. Since then, both improvements in the related technology by industry and regulatory actions have significantly reduced formaldehyde levels in workplaces and homes. It is also important to note that the IARC classifications are advisory "hazard identifications", not full risk assessments, that are challenged by the scientific community and are not legally binding.

In the European Union, formaldehyde is classified in category 3 – "Limited evidence of carcinogenic effect". The formaldehyde maximum exposure limits in the living space and workplace environment (occupational exposure) in various countries are presented in Table 1. It is seen that the limits valid in each country differ from one another even within the EU, while the values shown in parenthesis refer to new limits expected to be shortly in effect.

3. FORMALDEHYDE EMISSIONS FROM COMPOSITE WOOD PRODUCTS

Key element for the efforts to evaluate or control the contribution of wood products on the quality of indoor air is the means of measuring the actual formaldehyde emissions of a product. A variety of test methods for measuring product emission levels are applied worldwide, producing a corresponding variety of test results. Each method measures a slightly different emission characteristic and frequently produces results in different and non-interchangeable units. This proliferation of test methods and incomparable results often creates confusion among government regulators, consumers and industry personnel. One of the most common misunderstandings is that citing a formaldehyde level of a wood product is meaningless unless the test method and conditions are also cited. More specifically, the test methods used worldwide include[2]:

- The large/small chamber method, in which the test pieces of products under evaluation are placed in a special chamber simulating the prevailing conditions inside a building. Parameters such as the temperature, humidity, the air exchange ratio, the amount of samples placed are strictly prescribed and the method determines the "steady state" formaldehyde emission.
- The perforator method allows the determination of formaldehyde content of composite boards via extraction with toluene and it is the most widespread test procedure for measuring formaldehyde content from particleboards and MDF in Europe as far as the industry is concerned.
- The gas analysis method allows the determination of the formaldehyde emission rate from wood panels at a temperature of 60^{o}C.
- The flask method, which allows the determination of the formaldehyde emission from wood panels, whose test pieces are placed in a sealed flask, partially filled with water at a temperature of 40 ^{o}C.
- The desiccator method that is mainly used in Japan and it is similar to the flask method. In this case, a desiccator apparatus is used instead of the flask.

- The DMC (Dynamic Micro Chamber) method, which was developed in the USA and allows the fast determination of formaldehyde emission rate from wood panels under conditions controlled by a computer.

This wide variety of formaldehyde emission measurement methods as well as the absence of a commonly acceptable correlation among them creates barriers to the trade of composite wood-based panels from one country to another. For this reason the International Standards Organisation (ISO) is long making efforts to develop a universal standard measurement test based on the small chamber method ($1m^3$).

Based on the above-mentioned methods, there are different acceptable formaldehyde emission limits in every country or place of the world, depending on the product type. For example, the formaldehyde emission limits for particleboards and fibreboards are presented in Table 2.

The problem of reducing the formaldehyde emission of wood-based panels was addressed by numerous studies and research efforts in the last two decades. This led to the application of the following formaldehyde reduction strategies by the resin and board industries:

a) aminoplastic resins with low molar ratio of formaldehyde/urea or formaldehyde/amino groups,
b) aminoplastic resins in combination with substances scavenging the formaldehyde (formaldehyde catchers),
c) competitive binder systems such as phenolic resins or poly-isocyanate compounds,
d) post treatment of boards to reduce the formaldehyde emissions
e) restriction of the emission of boards by sealing their surfaces with special coatings or films (application of a diffusion barrier).

The lowering of the resin molar ratio substantially reduces the formaldehyde emission of wood panels. However, it negatively affects the resin bonding performance and can be only realized by using a completely different and more complicated resin synthesis technology than the typical one for standard high molar ratio resins. The use of proposed alternative binders increases the board production cost and induces application problems, as these systems require a different handling process. Moreover, there are doubts as to the degree and type of influence that these systems may have on human health and the environment. Last but not least, the post treatment of boards does not solve the emission problems at both the resin and board industrial production sites.

4. THE CHIMAR HELLAS APPROACH TO THE FORMALDEHYDE EMISSION REDUCTION

CHIMAR HELLAS S.A. is an innovating **technology provider** for the resin and wood-based panel industries and a pioneer in industrial research and development in the field of formaldehyde emission reduction. Following a process of continuously experimenting at laboratory, pilot and industrial scale, CHIMAR has concluded that the formaldehyde emission problem can be solved by the use of:

- **Innovative bonding/gluing systems** of resins and chemical additives (e.g. consisting of melamine-urea-formaldehyde resin (of high melamine content) in combination with a special additive-catalyst (for reactivity increase), the synergistic action thereby provides panels with the desirable properties such as high moisture resistance and low formaldehyde emission).
- **Advanced technologies for resin synthesis,** by better exploiting the active ingredients during resin synthesis (e.g. urea-melamine-formaldehyde resins (of low melamine content) that are produced in a special way so as to better activate the melamine used, to provide boards with very low formaldehyde emission ("zero emission", that is emission at the level of natural wood, emission class Super E0) and acceptable mechanical strength).
- **Resins based on natural products or by-products** (e.g. soya, tannin, starch, lignin from paper making) that combine the use of renewable raw materials with high bonding performance and reduced formaldehyde emission simultaneously.

All of the above-mentioned approaches have been optimised to offer cost savings to the resin and wood-based panels industries as well as to their end users-the consumers of such products. As it can be seen in Table 3, when a resin system belonging to the first of the above-mentioned approaches was applied in industrial particleboard production, it provided panels with formaldehyde emission at the level of natural wood (<2mg/100g of board[2]). In the same Table, the properties of the boards produced in parallel and by using a conventional resin system are also presented for the purpose of comparison.

5. CONCLUSIONS

Wood-based panels are very important materials for the construction of homes, buildings and furniture making. The possible harmful effect of formaldehyde emissions in indoor air must be successfully addressed. To this end, there has been much progress in the reduction of formaldehyde emissions of wood-based panels and other wood products during the last two decades. Moreover, the industry is preparing to deal with further reductions of the allowable limits due to the recent reclassification of formaldehyde by IARC.

CHIMAR HELLAS has succeeded in reducing the panel formaldehyde emissions by developing innovative resin systems, with components that are well studied and controlled, by advanced resin synthesis technologies as well as by the introduction of “natural” resins that are derived from renewable raw materials.

Through its worldwide experience, network of customers and collaborating research institutes, CHIMAR HELLAS develops and implements integrated solutions to the formaldehyde emission problem.

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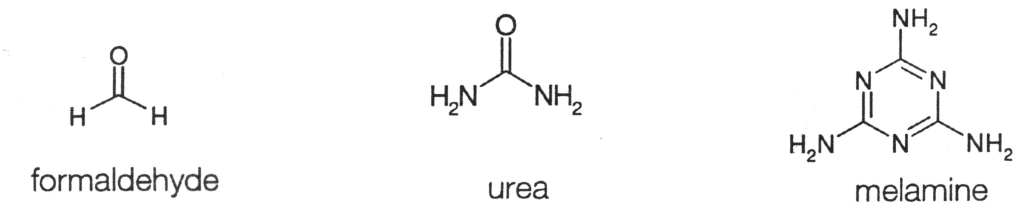

Picture 1. The structure of monomers forming the formaldehyde resins.

Table 1. Formaldehyde maximum exposure limits (MEL) in the living space and the workplace environment in various countries.

COUNTRY	FORMALDEHYDE MEL, ppm LIVING SPACE	FORMALDEHYDE MEL, ppm WORKPLACE
Denmark	0.120	0.30
Finland	0.120	0.30
Norway	0.100	0.50
Sweden	0.100	0.50
Austria	0.100	0.50 (0.30)
Germany	0.100	0.50 (0.30)
Switzerland	0.100	0.50
Great Britain	-	2.00
Belgium	-	0.30
Netherlands	0.100	1.00 (0.12)
France	-	0.50
Spain	-	0.30
Italy	-	0.30
Greece	-	2.00
Australia	0.100	1.00
Canada	0.100	0.30-2.00
U.S.A	0.100	0.75
WHO	0.082	-

Table 2: Upper formaldehyde emission limits for particleboards (PB) and medium density fibreboards (MDF) per country.

COUNTRY	STANDARD	METHOD	BOARD CLASS	LIMIT VALUE
Europe	EN 13986	Chamber ENV 717-1 Perforator EN 120	E1	≤0.1ppm ≤8mg/100g
			E2	>0.1ppm >8 - ≤30mg/100g
Australia	AS/NZS 1859.1 & 2	Desiccator AS/NZS 4266.16 Perforator AS/NZS 4266.15	E1	PB: ≤1.5mg/L ≤8mg/100g MDF: ≤1.0mg/L ≤9mg/100g
			E2	PB: >1.5 - ≤5.4mg/L >8 - ≤30mg/100g MDF: >1.0 - ≤3.3mg/L >9 - ≤30mg/100g
N. America	ANSI A208.1 & 2	Large chamber ASTM E1333	Single class	≤0.3ppm
Japan	JIS A 5908 & 5905	Desiccator JIS A 1460	F** F***/E0 F****/SE0	≤1.5mg/L ≤0.5mg/L ≤0.3mg/L

Table 3. Industrial trial for the production of particleboards with "zero" formaldehyde emission.

BOARD PROPERTY	CONVENTIONAL RESIN SYSTEM	CHIMAR RESIN SYSTEM
Density, Kg/m^3	674	670
Tensile strength (IB), N/mm^2	0,72	0,70
Bending strength (MOR), N/mm^2	20,2	20,3
Thickness swelling after immersion in water for 24 h, %	13,8	13,7
Formaldehyde, mg/100g of board (perforator test)	7,5	1,9