European Approach to Particleboard and MDF adhesives

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SUMMARY

In this work, the adhesives used in the European particleboard and MDF industry are presented. The structure of the particleboard and MDF market in Europe in relation to the adhesive type and product application is discussed as well. It is notable that new markets for particleboard and MDF - known as non-furniture markets - are developing in Europe at a very fast rate. Newly developed resin systems and trends affecting the industry are also presented.

INTRODUCTION

In Europe, aminoplastic resins are the most important adhesives for the different types of wood-based panels, mainly particleboard and medium density fibreboard (MDF). Whereas urea-formaldehyde (UF) resins are mainly used for interior-use boards, the incorporation of melamine provides resins with a lower susceptibility against hydrolysis, that is, with a better water and weather resistance. Nearly all kinds of requirements can be met with these aminoplastic resins. In addition, new products such as moisture-resistant boards, fire-retardant boards, exterior-use boards, etc. have showed a rapid growth in the European particleboard and MDF market in the recent years.

Aminoplastic resins with a low content of formaldehyde fulfill the stringent regulations that have been enforced in Europe during the last decade concerning the subsequent formaldehyde emission. In addition, boards with an extremely low formaldehyde emission, similar to that of natural wood, can be produced specifically by means of special melamine-urea-formaldehyde (MUF) resins. Melamine-urea-phenol-formaldehyde (MUPF), phenol-formaldehyde (PF) and polymeric methylene di-isocyanate (PMDI) resins are also used in Europe. However, the quantities of MUPF, PF and PMDI resins consumed today by the European particleboard and MDF industry are relatively small.

PARTICLEBOARD & MDF ADHESIVES: CURRENT STATUS

In Europe, most of the resins currently used in the particleboard and MDF industry are formaldehyde-based adhesives (UF, MUF, etc.) which have a molar ratio of Formaldehyde:Urea (F:U) between 1.05 and 1.20 [1,2,3,4]. In MDF, this F:U ratio in some cases can be smaller (0.90-1.00). It is to be noted that only 10 years ago, the majority of the resins used had a molar ratio as high as 1.4-1.6 [3,4]. The major reason for this significant reduction over the years was the attempt of resin manufacturers to decrease the formaldehyde emission. The driving force behind that has been consumer opinion along with legal regulations.

The reduction of the molar ratio was initially achieved by introducing in the resin production process one or two extra steps in the urea addition. The urea reacted with the residual formaldehyde, and the free formaldehyde emitted from the board was drastically reduced. However, this outcome had many negative side effects. The plants had to tolerate longer press times, tighter moisture control, higher glue factors in addition to the fact that the mechanical properties and water resistance of the boards were lowered. Thus, further developments to address these problems included the addition of a small quantity of melamine (usually 1-4%). This although increased the production cost, it proved to be quite successful. Such MUF resins are generally more forgiving with the process variations than straight UF resins. For formaldehyde-based resins, the above approach appears up to day to be the only way to produce either particleboard or MDF with low formaldehyde emission without the use of any additives [1,4].

In meanwhile, the resin industry has invested much in the research of low Free Formaldehyde (FF) straight UF resins [4,6,7]. New technologies of such UF resins have recently come out in the European market by a small number of resin producers. These manufacturers claim that they combine the emission advantages of the FF resins with the performance advantages of the high molar ratio resins. Such resins give boards with low formaldehyde emission with the addition of formaldehyde catchers (or scavengers) [4,6,7]. It appears after all that the resin formulation changes to the direction of reducing molar ratio are at a practical limit.

Formaldehyde catchers are widely used in the European particleboard and MDF industry in order to reduce the formaldehyde emission. There are actually many practical advantages in using a catcher system. One advantage to note is the flexibility it provides to the plant manager to vary its quantity, and subsequently, control the reduction of formaldehyde emission according to the conditions and production requirements [1,3]. However, the major advantage of a catcher system is the fact that it provides a much more efficient system than that of a straight resin' [4]. The formaldehyde catchers can be in most cases tailor-made to meet the needs of the particular plant. They are used up to a maximum of 25% on the resin, achieving thus reduction in emission up to 60% [4]. Experience in Europe has shown that instead of using a very low molar ratio resin, one can achieve better results by using a system of an equivalent molar ratio, which is a combination of a higher molar ratio UF resin and a formaldehyde catcher [1,4].

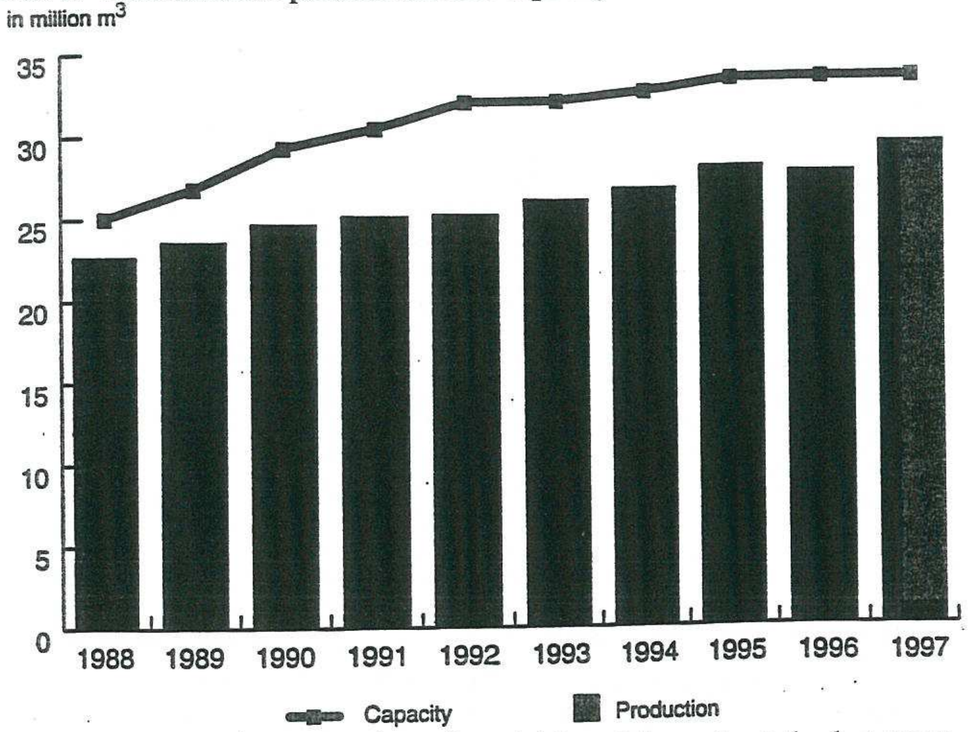
The hardeners (catalysts) used in the past in Europe were mostly ammonium chloride and ammonium sulphate. During the last few years, ammonium sulphate is used instead, at least in most central and northern European countries, because the use of ammonium chloride has been forbidden for environmental reasons. Both of the above-mentioned hardeners react with the free formaldehyde in the resin and liberate either hydrochloric or sulfuric acid which speeds up the polymerization reaction by lowering the pH. A decade ago, the UF resins used had a molar ratio between 1.4-1.6 and fairly high levels of free formaldehyde. However, since the trend today is to use resins with significantly lower formaldehyde emission, this level is insufficient to produce a significant pH drop in case that ammonium salts are used as catalysts. Such problems can be overcome by using new special hardeners that will not rely on the available formaldehyde in order to generate acidity [1,3,4]. Their effectiveness therefore will not be influenced by the free formaldehyde in the resin used. The development of such special catalysts is been carried out by some resin manufacturers.

Notably, in the European particleboard industry today, the main requirement of the UF system is speed, since the modern continuous presses can run extremely fast. The speed achieved up to now can be as low as 3.8 sec/mm. The UF resins applied require though a modified cooking procedure and special additives. This is considered to be a major breakthrough in the field.

EUROPEAN PARTICLEBOARD MARKET

The particleboard industry experienced a positive development during 1997 [9]. The overall level of production in FESYP (European Federation of Associations of Particleboard Manufacturers) member countries in 1997 amounted to some 29.6 million cubic meters. Fig. 1 outlines the particleboard production and capacity from 1988-1997 [9].

FIG. 1: Particleboard production and capacity 1988-1997



The production and consumption of particleboard throughout the last years in Europe have presented constantly increasing growth rates. In 1997, there was an increase of approx. 8% as compared to that of 1996. There were 169 particleboard production plants in the 18 FESYP member countries (Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Italy, Latvia, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, United Kingdom and Ireland). They provided employment for some 25,000 people. The particleboard production capacity in Europe per country is shown in TABLE 1 [9]. It is estimated that the key figures of the particleboard industry in the countries of Central and Eastern Europe in 1996 and 1997 were those presented in TABLE 2 [9].

TABLE 1: Particleboard production in FESYP member countries

	1993 1,000 m³	1994 1,000 m³	1995 1,000 m³	1996 1,000 m³	1997 1,000 m³	97:96
Austria	1,592	1,598	1,640	1,650	1,690	*2.4%*
Belgium	2,424	2,435	2,421	2,558	2,567	*0.4%*
Cyprus	20	20	20	20	19	*-7.0%*
Denmark	232	265	285	295	303	*2.7%*
Finland	439	477	484	498	475	*-4.6%*
France [1]	2,610	2,874	3,103	3,188	3,465	*8.7%*
Germany	7,935	8,616	8,900	8,583	9,200	*7.2%*
Greece	350	320	338	335	338	*0.9%*
Italy	2,250	2,202	2,450	2,205	2,750	*24.7%*
Latvia [2]	101	148	130	140	150	*7.1%*
Norway	313	372	389	384	393	*2.3%*
Poland [1]	1,143	1,291	1,466	1,652	1,996	*20.8%*
Portugal	575	757	650	695	859	*23.6%*
Slovenia	216	195	294	246	250	*1.6%*
Spain	1,660	1,730	1,605	1,690	1,815	*7.4%*
Sweden	597	609	632	576	612	*6.3%*
Switzerland	689	595	491	495	501	*1.3%*
United Kingdom [3]	1,756	1,812	2,118	2,164	2,175	*0.5%*
TOTAL	**24,902**	**26,316**	**27,416**	**27,374**	**29,558**	***8.0%***
Total EU (15)	22,420	23,695	24,626	24,437	26,249	*7.4%*
Total EFTA	1,002	967	880	879	894	*1.7%*
Total Others	1,480	1,654	1,910	2,058	2,415	*17.3%*

1) including OSB
2) FAO/ECE Timber Bulletin, volume 50/6, 1997
3) including OSB and mineral bonded

TABLE 2: Key figures of the particleboard industry in the countries of Central and Eastern Europe

Country	Production			Imports			Exports			App. Consumption		
	1996 1,000 m³	1997 1,000 m³	97:96 %	1996 1,000 m³	1997 1,000 m³	97:96 %	1996 1,000 m³	1997 1,000 m³	97:96 %	1996 1,000 m³	1997 1,000 m³	97:96 %
Bulgaria[1]	120	120	*0.0*	n.a.	n.a.		15	15	*0.0*	n.a.	n.a.	
Czech Rep.[1]	635	650	*2.4*	68	65	*-4.4*	312	315	*1.0*	391	400	*2.3*
Estonia[1]	143	165	*15.4*	21	25	*19.0*	93	107	*15.1*	71	83	*16.9*
Hungary	386	429	*11.1*	33	40	*21.2*	132	150	*13.6*	287	319	*11.1*
Latvia[1,2]	140	150	*7.1*	0	0		90	100	*11.1*	50	50	*0.0*
Lithuania	110	168	*52.7*	31	41	*32.3*	70	134	*91.4*	71	75	*5.6*
Poland[2]	1.652	1.996	*20.8*	483	520	*7.7*	15	106	*606.7*	2.120	2.410	*13.7*
Romania	248	217	*-12.5*	16	10	*-37.5*	10	11	*10.0*	254	216	*-15.0*
Slovak Rep.[1]	245	250	*2.0*	20	20	*0.0*	27	26	*-3.7*	238	244	*2.5*
Russian Fed.[1]	1.460	1.400	*-4.1*	53	50	*-5.7*	100	110	*10.0*	1.510	1.340	*-11.3*
Slovenia[1,2]	246	250	*1.6*	37	40	*8.1*	73	75	*2.7*	210	215	*2.4*
Total	**5.385**	**5.795**	***7.6***	**762**	**811**	***6.4***	**937**	**1149**	***22.6***	**5.202**	**5.457**	***4.9***

1) FAO/ECE Timber Bulletin, volume 50/6, 1997
2) FESYP members

The adhesives used in the European particleboard industry are mostly UF and MUF resins, but MUPF, PF and PMDI resins are also used for special applications.

Specific standards have been adopted by the CEN (European Committee for Standardization) for the different particleboard grades produced today in Europe. For particleboards, specific requirements - depending upon the thickness range - have been issued for each particleboard type. The types of particleboards are those outlined in TABLE 3 [9].

TABLE 3: Types of particleboard in Europe

Board type	Product application	Standard
P2	General purpose boards for use in dry conditions	EN 312-2
P3	Boards for interior fitments (including furniture) for use in dry conditions	EN 312-3
P4	Load-bearing boards for use in dry conditions	EN 312-4
P5	Load-bearing boards for use in humid conditions	EN 312-5
P6	Heavy duty load-bearing boards for use in dry conditions	EN 312-6
P7	Heavy duty load-bearing boards for use in humid conditions	EN 312-7

The volumes of particleboard in each of its market sectors are not freely available in Europe. Neither FESYP nor other official source has such data.

It is estimated that approximately 90% of all particleboard produced in Europe is that of standard industrial grade. The majority of this falls within the 16 and 18 mm thickness grades. Straight UF resins of low molar ratio

(1.05-1.10) are used in this category. The glue factor is at the range of 7-8%. The press times typically are between 4-8 sec/mm. Most of the particleboard standard grade belongs to E1 class (see TABLE 12) and is used for interior applications.

Another fast-growing market in Europe is that of moisture resistant particleboard. Strict requirements for moisture resistant boards have been defined according to the product application [9]. The specific tests for moisture resistant boards are the following:

V-313: Cyclic test in humid conditions (standard EN 321) which requires measurement of internal bond after a specific cyclic test (TABLE 4) [9] &

V-100: Determination of moisture resistance - Boil test (standard EN 1087-1) which requires measurement of internal bond after a specific boil test (TABLE 5) [9].

Moisture resistant particleboard (V-313 particleboard) is at present the major special grade with volumes estimated at around 5% of the total market. Such a board is designed for use in humid conditions. This market has been developed substantially in recent years, mostly in France, Belgium, Holland, Italy and Scandinavia. V-313 particleboard is produced with MUF resins with a melamine addition of 12-20%. Such resins have a molar ratio of 1.10-1.20. The glue factor that is usually applied is at the range of 12-13% on dry wood. The press time used ranges enough (6-10 sec/mm).

The other moisture resistant particleboard, which is used in more extreme humid and load-bearing conditions than V-313 particleboard, and qualified as V-100, represents one more special grade in Europe. Its market volumes are small though. In general, V-100 test requirements are stricter than those of V-313. It is estimated that this market is ca. 1-2% of the total market. This special market has been developed largely in recent years in Germany. V-100 particleboard is made usually with MUPF resins which contain melamine at a percentage of around 23%. The phenol content is approximately 5%. Such resins have a molar ratio of 1.05-1.10, while the glue factor is at the range of 13-14%. A very small group of resins used also in Germany for this particular particleboard grade is that of PF resins. Their phenol content is around 9-10%. Such PF-bonded particleboards have a very low formaldehyde emission assuming that all free formaldehyde present in the resin system has been incorporated into the PF resin by means of proper hardening conditions and hot stacking of freshly pressed boards. For V-100 particleboard, the press times are in the range of 6-10 sec/mm.

Fire-retardant particleboard is another special grade in Europe. Such a board is used in public buildings where fire spread must be controlled to comply with fire safety regulations. Although this particleboard grade is relatively small (<3%), a trend for further development of this market appears lately. The resins used for this grade are MUF resins with a melamine addition of approx. 13-15%. Such resins have a molar ratio of around 1.20. The glue factor is ca. 13-15%. The fire retardants used such as ammonium phosphates, boron-based compounds, etc., are added to a 13-15% on the dry wood basis. Low press times can be 9-11 sec/mm, while higher press times in this category are usually in the range of 12-13 sec/mm.

Particleboards of E1 class (see TABLE 12) using PMDI adhesives are also produced in Europe. This production process was introduced some years ago and has a few disadvantages (e.g. sticking, high cost). Today, there are a couple of plants in Europe producing regularly this type of board. Isocyanate resins are used in combination with UF resin; the UF being used particularly in the surface in order to avoid any sticking problems. However, such resins are expensive, and although smaller quantities are used, such boards are more expensive than standard UF-bonded boards. This market is very small, possibly less than 1%. In addition, in the production of V-100 or V-313 boards, PMDI resins in the core layer in combination with PF or MUPF resins in the surface layer are also used in a few plants.

TABLE 4: European standard (EN 321) relating to moisture resistant V-313 particleboard (V-313 cycling test)

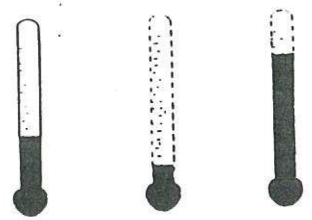
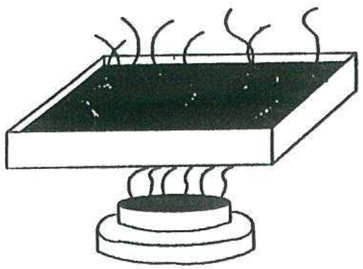
 72 h 20°C · 24 h -12°C · 72 h 70°C	EN 321 Cyclic test in humid conditions	1.) Conditioning at 20°C and 65 % relative humidity 2.) 3 cycles of I. 72 h in water of 20°C II. 24 h deepfreeze at -12°C III. 72 h drying oven at 70°C 3.) Reconditioning at 20°C and 65 % RH	before treatment: length of testpiece = a (mm) width = b (mm) thickness = t_1 (mm) after treatment: maximum force = F_{max}(N) thickness of test piece = t_2 (mm)	$\sigma = F_{max}/(a \times b)$ (N/mm²) (cf. EN 319) $G_1 = [(t_2 - t_1)/t_1] \times 100$ (%) (cf. EN 317)

TABLE 5: European standard (EN 1087-1) relating to moisture resistant V-100 particleboard (V-100 boil test)

Figure	Number - Title	Treatment of test pieces	Measurements	Calculation of results
	EN 1087-1 Moisure resistance tests Part 1: Boil test	1. conditioning at 20°C and 65% relative humidity 2. immersion in water at 20°C 3. 1.5 h heating up to 100°C 4. 2 h. boiling 5. 1 to 2 h cooling down to water temp. of 20°C	before treatment: length of test piece = a (mm) width = b (mm) after treatment maximum force = F_{max} (EN319) (N)	$\sigma_{\perp} = F_{max} /(a \times b)$ (N/mm^2)

Lately, another particleboard grade which is under discussion is that of F-zero (F-0). This is a really brand new market. Up to day, it has been believed that such a particleboard grade could be only produced by using PMDI or PF resins that have zero-formaldehyde emission. In fact, formaldehyde emission is not zero because of the emission of formaldehyde from the dried wood. In addition, many proposals of regulations have been published for the so-called 'F-zero' limits [2,4,6,7]. The actual discussion concerning the subsequent formaldehyde emission is briefly summarized in TABLE 6.

TABLE 6: Discussion concerning subsequent formaldehyde emission

UZ 38: for finished products	
	- raw board (4.5 mg/100g by the perforator method)
UZ 76 (Blue Angel):	- 3.0-3.2 mg/100g by the perforator method
F-zero limit:	< 2.0 or 2.5 mg/100g (new proposal)

For UZ 76, in Germany, the so-called 'Blue Angel' with desired free formaldehyde emission of less than 0.05 ppm, which corresponds to 3.0-3.2 mg/100g dry board (at moisture content of 6.5%), an essentially formaldehyde-free board has been developed. As a matter of fact, 'Blue Angel' is a label that is awarded by the German Health and Ecology Ministry to environmentally friendly products. Today, wood-based panels such as particleboard, used for finished house construction are granted with this 'Blue Angel' certification.

F-0 particleboards are produced today in Europe by the use of MUF resins. This market is below 1% of the total volume. The MUF resins used for this grade are of low molar ratio (around 0.80-0.90) and a melamine addition of approx. 15-23%. The press times are around 10-12 sec/mm.

In overall, the particleboard market in Europe is summarized as shown in TABLE 7.

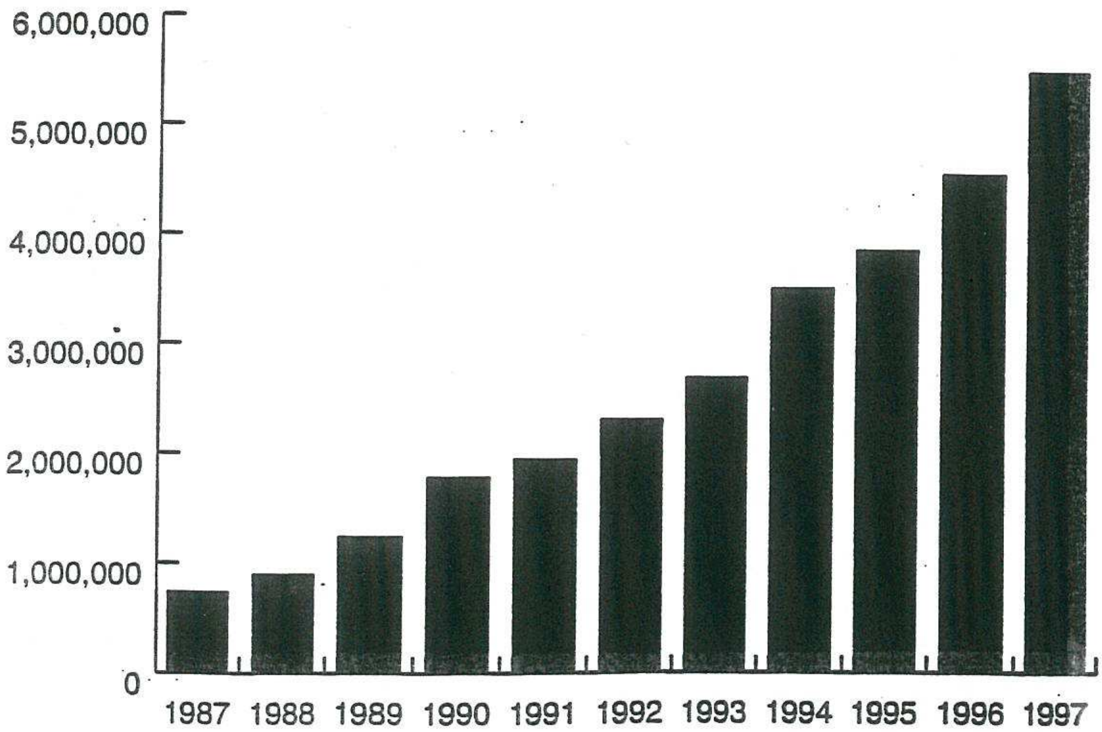
TABLE 7: Volume (% of total) of particleboard products in Europe

Product type	% of total volume
Standard industrial grade	≈ 90 %
Moisture resistant grade (V313, V100)	≈ 6-7 %
Fire retardant grades	< 3 %
Zero-added formaldehyde	< 1 %
F-zero grade	< 1 %

EUROPEAN MDF MARKET

MDF was first introduced in Europe in the mid 1970s with the first sales in the United Kingdom occurring in 1976. Fig. 2 outlines the rapid growth in the production of MDF from 1987-1997 [9].

FIG. 2: European production of MDF in m^3



The production and consumption of MDF throughout the last years in Europe have presented very rapid growth rates. 1997 was a very positive year, since MDF had a 20% increase compared to 1996. The total production volume was ca. 5,451,000 m^3 [9]. Industry analysts predict similar growth rates for the next three years as many new lines are now being established, while capacity on recently installed lines is being optimized [9].

In 1997, there were 43 MDF production plants with 52 press lines in the 18 FESYP member countries. The MDF production capacity in Europe per country is presented in TABLE 8 [9].

TABLE 8: MDF production capacity in Europe per country

Country	Production Capacity (m^3)	
	1-1-1995	31-12-1997
Germany	**967,000**	**1,780,000**
Italy	**910,000**	**1,240,000**
Poland	**154,000**	**480,000**
Spain	**580,000**	**472,000**
France	**430,000**	**463,000**
Great Britain	**370,000**	**430,000**
Portugal	**89,000**	**424,000**
Ireland	**300,000**	**310,000**
Luxemburg	-	**250,000**
Belgium	-	**200,000**
Denmark	**100,000**	**100,000**
Sweden	-	**90,000**
Austria	**80,000**	**80,000**
Greece	**65,000**	**65,000**
Czech Republic	**60,000**	**62,000**
Slovenia	**55,000**	**55,000**
TOTAL	**4,160,000**	**6,501,000**

It has been shown that the applications for MDF outside the furniture industry (interior-use MDF) are more developed in Europe than elsewhere (TABLE 9) [10]. Approximately 33% of the European MDF production was used in 1997 in non-furniture applications compared to 20% in the USA [10].

TABLE 9: Percentage of furniture and non-furniture MDF produced by region

Region	Furniture	Non-furniture
Europe	67 %	33 %
North America	80 %	20 %
Asia	68 %	32 %

In Europe, there are today 18 major groups producing MDF. All produce standard industrial grade MDF, while many are producing various grades of special products (TABLE 10) [10]. Half of the groups produce moisture resistant MDF, thin MDF, light and super-light MDF. Special products include exterior-use MDF, fire-retardant MDF and high density MDF.

The adhesives used in the MDF industry in Europe are mostly UF resins, but melamine-fortified (1-4%) UF resins (MUF) are also used in many plants. Zero-added formaldehyde MDF bonded with PMDI resins comprises a very small market in Europe (< 1%).

TABLE 10: Level of various MDF products by industry group

Product type	No. of groups	% of groups
Standard MDF	18	100 %
Cut to size MDF	12	67 %
Faced MDF (melamine, foil, etc.)	12	67 %
Thin MDF (< 6mm)	10	56 %
Moisture resistant MDF	9	50 %
Light and super-light MDF	9	50 %
Lacquered/Printed MDF	9	50 %
Flooring quality MDF	6	33 %
Fire retardant MDF	5	28 %
Zero-added formaldehyde MDF	5	28 %
High density MDF	5	28 %
Exterior grade MDF	4	22 %

The volumes of the various MDF grades are also - as in particleboard - not freely available. An estimation of the current MDF market structure in Europe is outlined in TABLE 11 [10].

It is estimated that approximately 60-65% of all MDF produced is standard industrial MDF with the majority being at the 18 mm thickness grade. UF and MUF (1-4% melamine) resins of low molar ratio (0.95-1.00) are mostly used in this category. The press times vary between 9 and 11 sec/mm.

Moisture resistant MDF and MDF for laminated flooring are the two main special grades at present with volumes estimated for each at ca. 10% of the total market. Moisture resistant MDF is a product designed for use in humid conditions. It is successfully used for kitchen furniture, bathroom furniture, window boards, etc. This market has been developed substantially in recent years in UK and Ireland. Such MDF (known as MDF-H) is produced with MUF resins which contain melamine at a percentage of ca. 12-15%. The press times used are around 9-11 sec/mm. For this grade, much scope exists for the continued growth of moisture resistant MDF as a substitute for conventional products in joinery applications [10].

TABLE 11: Volume (% of total) of special MDF products in Europe

Product type	% of total volume
Standard industrial grade	≈ 60-65 %
Moisture resistant grade	≈ 10 %
Flooring quality	< 10 %
Fire & flame retardant grades	< 3 %
Zero-added formaldehyde	< 1 %
High density	< 5 %
Exterior grade	< 3 %

Wood constitutes about 6% of the total flooring market in Europe. MDF itself represents ca. 80% of the total laminated flooring market in Europe. Laminated flooring MDF has achieved spectacular growth over the past few years. Introduced in Sweden in the 1980s, this MDF grade has been successfully used as a substrate for a wide variety of overlay materials such as wood veneers, high pressure laminates and melamine impregnated papers. MDF used for this application is made with 3-5% melamine-fortified UF resins, since higher moisture resistance is highly required. Press times vary between 9 and 12 sec/mm.

Exterior grade MDF (known as MDF-H2) is designed for use in exterior conditions. It is used in a wide range of applications including external signs, shop fronts, door parts, garden furniture, etc. MUF (12-17% melamine) resins are usually used for this special grade. Such boards must pass the V-313 test to be classified as exterior grade MDF. The press times used in this case are 9-11 sec/mm. PF resins for MDF products are not currently used in Europe as far as it is known.

Another special market is that of fire and flame retardant MDF (FR MDF). Such a product is used in public buildings where fire spread must be controlled to comply with fire safety regulations. Unfortunately in Europe today, the MDF panel requirements for such uses tend to vary considerably. A need for a common European standard is mandatory in this case. Although this MDF grade is relatively small (< 3%), there is being lately a trend for further development. The resins used for this grade are mostly of UF type. The glue factor is higher though (≈15%), while large proportion (6-10%) of the FR agents (ammonium sulfates, phosphates, boron-based compounds, etc.) is usually applied [9].

Unfortunately, as mentioned previously, panel requirements tend to vary considerably for each country and achieving certification takes considerable time and resources. It appears today that the development of a Single

Burning Item (SBI) test as a common European standard for FR-treated particleboard and MDF will remove the current obstacles.

FORMALDEHYDE EMISSION FROM PARTICLEBOARD & MDF

Formaldehyde is among the major indoor air pollutants. The main source of formaldehyde emission indoors comes from the formaldehyde of particleboard and MDF products. One of the first steps taken to reduce pollution from formaldehyde was to standardize the emission from particleboard into three classes: E1, E2 and E3 (TABLE 12) [5,8]. However, acceptable levels of formaldehyde emission have been continuously reduced in Europe over the last years. The corresponding lower limit for MDF (for E1 class) is 7.0 mg/100g. For both particleboard and MDF formaldehyde emission, a correction of the perforator value to 6.5% board moisture content should be made.

TABLE 12: Classification of particleboards according to their formaldehyde emission

Class	Concentration (ppm) in 40 m^3 chamber [1]	Perforator value (mg/100g) [2]
E1	0.015 - 0.1	6.5 - 10
E2	0.1 - 1.0	10 - 30
E3	1.0 - 2.3	30 - 60

[1] Chamber method, prEN 717-1

[2] Perforator method, EN 120

The formaldehyde emission indoors has been extensively researched since the early 70's. Occupational exposure limits for formaldehyde concentration were first issued in several European countries in an attempt to handle possible problems. Residential standards were also determined in the U.S. and other countries [1,3,8].

Basis of all regulations had been the recommendation of the German Federal Health Agency in 1977 for a maximum formaldehyde concentration in the air of 0.1 ppm (= 0.12 mg/m^3). As a consequence, there is now a clear status concerning the subsequent formaldehyde emission from all wood-based panels given with the German Regulation of Hazardous Substances (now German Regulation of Prohibition of Chemicals) and the German Federal Health Code [6,8]. It was the big effort in research and development in the chemical industry, and the harmonic cooperation with the wood-based panels industry, which made it possible to overcome the problem of formaldehyde emission.

It is apparent from TABLE 13 [3] that the formaldehyde concentration limits in most of the industrialized countries have been dramatically reduced over the last 20 years in order to keep the air clean and protect the health of humans. Characteristic is the fact that the formaldehyde contents of the wood-based panels today are 10 to 15 times lower than those before 15 years [1,4]. Therefore, it appears that the problem of formaldehyde emission from wood-based panels has been limited to a very significant degree.

In TABLE 14, it is shown that for workplace exposures, the allowable formaldehyde concentration (Occupation Exposure Limit) for 13 countries ranges from 0.3 ppm to 2.0 ppm, with the majority of them to range between 0.5 and 1.0 ppm [4,5,8]. These exposure limits in most industrialized countries are reasonably very strict. Also, the lowest occupational exposure limit for the living space in most countries is around 0.1 ppm. It is obvious from TABLE 14 that the acceptable exposure level in ambient air is usually 5-10 times lower than the exposure limit in workplace, except for three countries. There are also three other countries with no limits for the living space.

TABLE 13: Maximum exposure limits for formaldehyde in the workplace environment in various countries (as in year 1976, 1985 and 1998)

Country	1976 Formaldehyde concentration (ppm)	1985 Formaldehyde concentration (ppm)	1998 Formaldehyde concentration (ppm)
USA	5.0	3.0	1.0
Denmark	5.0	1.0	0.3
Finland	5.0	1.0	0.5
Norway	-	1.0	0.5
Sweden	-	1.0	0.5
Austria	-	-	0.5
Germany	5.0	1.0	0.5
Switzerland		1.0	0.5
United Kingdom	10.0	2.0	2.0
Belgium	-	2.0	1.0
France		-	2.0
Australia	-	-	1.0
Canada	-	-	1.0

TABLE 14: Maximum exposure limits (MEL) for formaldehyde in the living space and the workplace environment in various countries (as in 1998)

Country	MEL in the living space (ppm)	MEL in the workplace (ppm)
USA	0.1	1.0
Denmark	0.12	0.3
Finland	0.12	0.5
Norway	0.1	0.5
Sweden	0.2	0.5
Austria	0.1	0.5
Germany	0.1	0.5
Switzerland	0.1	0.5
UK	--	2.0
Belgium	--	1.0
France	--	2.0
Australia	0.1	1.0
Canada	0.1	1.0

Another problem - which has not yet solved - is how to measure the formaldehyde emission from particleboard and MDF products. Today in Europe, three different methods for determination of formaldehyde emission have been issued by the CEN. These methods are the following ones [5,8,9]:

- Extraction method called the perforator method (EN 120)

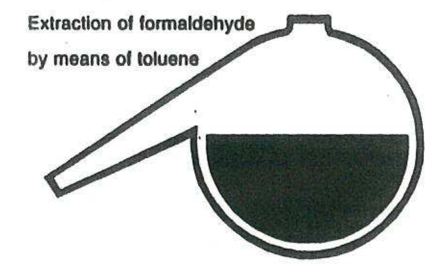
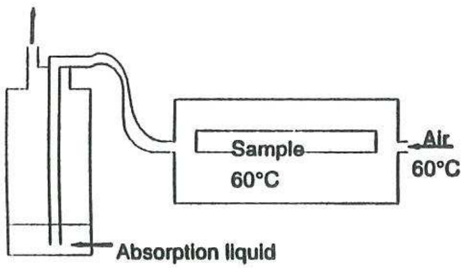
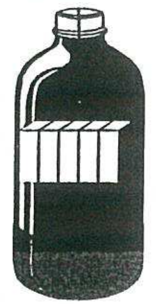
- Formaldehyde release by the gas analysis method (EN 717-2)
- Formaldehyde release by the flask method (EN 717-3)

One more standard for determination of formaldehyde emission (prEN 717-1: Determination of formaldehyde release - Formaldehyde emission by the chamber method) is currently being translated and should be officially issued next year. However, exact correlations should be defined between the steady state concentration test in a small or a big climate chamber and the laboratory test methods such as perforator, gas analysis and flask method, or even the desiccator method. It is apparent that the particleboard and MDF industry needs today quick and reliable test methods for supervising production and for assuring compliance with the regulations.

CURRENT DEVELOPMENTS: A NEW RESIN SYSTEM

A unique Free Formaldehyde process with a conventional formaldehyde-based resin has been lately developed by the company **A.C.M. Wood Chemicals** (new F-0 system). This system is based on a combination of an MUF resin, a formaldehyde catcher and a special hardener. This resin with a low molar ratio of ca. 0.75-0.90 and a melamine addition of 10-18%, can achieve industrial production of particleboards with free formaldehyde emission values below 2.0 mg/100g dry board (Perforator value) without any deterioration in the board properties, and without increasing press times and amount of resin. The press times used in this innovative process are in the range of 10-12 sec/mm.

TABLE 15: European standards relating to particleboard and MDF formaldehyde emission (as of April 1998)

	EN 120 Determination of formaldehyde content: Extraction method called the perforator method	± 100 g unconditioned test specimen of 25 mm x 25 mm to be prepared for extraction	total amount of formaldehyde in extract, by means of spectrophotometrics (mg/l)	calculation of amount of formaldehyde in 100g dry board from the amount of formaldehyde in the extract (mg/100g)
	EN 717-2 Determination of formaldehyde emission - Part 2: Formaldehyde release by the gas analysis method	test specimen 400 mm x 50 mm (sealed edges) in gas analysis apparatus at 60°C	G_1=emission during 1st h G_2=emission during 2nd h G_3=emission during 3rd h G_4=emission during 4th h	G_1 is not taken into consideration (test specimen is being heated up to 60°C) gas analysis value $G = (G_2 + G_3 + G_4)/4$ (mg/hm²)
	EN 717-3 Determination of formaldehyde emission - Part 3: Formaldehyde release by the flask method	test pieces 25mm x 25 mm (sealed edges) in airtight flask with 50 ml of water at 20°C, put in an oven at 40°C	A_S = absorbance of analysed solution from the flasks A_B= absorbance of analysis with distilled water f = slope of the calibration curve H = moisture content of test pieces m = mass of test pieces	$F_V = (A_S - A_B) \times f \times 50 \times 10 \times (100 + H)/ m$ (mg/kg)

For the authors

The authors of this article are employed by the company **A.C.M. Wood Chemicals Plc.** which is an industrial company that is entirely and exclusively dedicated to the chemistry applied to the wood-based panels industry. A.C.M. Wood Chemicals is a major licensor in chemical know-how and binder processes, while it possesses an international experience in adhesives for wood-based panels.

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