OPTIMISATION OF DRY MORTAR PRODUCTS PROPERTIES BY APPLICATION OF ACRYLIC FIBRES IN CONSIDERATION OF FIBRE LENGTH / DIAMETER

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ABSTRACT

Dolan GmbH, an undertaking of the Lenzing Plastics Group, is active in the field of reinforcement of composites since 80 years. Dolan GmbH, which produces 15,000 tons of acrylic fibres every year, offers an innovative range of products, mainly comprising ACRYLIC fibre specialities for garden furniture, car top covers and technical fibres for the reinforcement of concrete, mortar, asphalt, fibred concrete products and automotives. In July 2008, the newly founded EPG – GmbH commissioned a new production line for 5,000 tons of precursor for the fabrication of carbon fibres.

Dolan GmbH is the only fibre manufacturer that combines its know-how pertaining to fibre production, fibre structures and fibre finishing for varied technical end uses on one site in Germany. This article throws light upon the use of process fibres / reinforcement fibres for dry mortar products and will prove to be a great help to the lab assistant in the selection of the appropriate fibres of the correct quality and quantity. A number of relevant descriptions in the literature mention that a homogenous distribution of synthetic fibres in different composites has positive effects during the green status phase (Grün-Stand Phase), the actual hardening process, as well as on the hardened product. However, these published research results are generally limited to comparing different fibre materials with respect to only one starting parameter, e.g. the length, and are also limited mainly to one material - concrete and its material properties. The distribution of fibres as a key function, depending upon the density of fibres [∂], length of fibres [mm] and the diameter of fibres [µ], and the resultant fibre quantity [fibres / gr.] or the fibre surface [m²/gr] are the decisive features for the resulting property of a solid material. The dispersibility of fibres in dry mortar as well as the processing criteria for wet mixing were tested. The final mixture, consistency, viscosity and the spread value / slump were the decisive criteria for the selection of appropriate acrylic fibres. The properties of hardened mortar were recorded in conformance with DIN by conducting the pressure test [DF] and the three-point flexural strength test [BZ] and compared with a zero mixture, i.e. a mixture without fibres.

The research was conducted in collaboration with Dolan GmbH, Sakret GmbH in Painten and the Fachhochschule Regensburg (Technical college at Regensburg). The thesis was edited by Florian Fleischmann.

KEYWORDS

Mixing procedure; PAN -Fibre; Compression strength; bending strength; Fibre dispersion.

1. INTRODUCTION

The fibres used in the seventies, which were developed by Hoechst Ag for technical applications, were made of homo-polymer polyacrylonitrile. The ratio of acrylonitrile was > 99.6 weight percentage. These high-performance fibres, called homo-polymer PAN in short, which are highly resistant to lyes and acids, are available in the market even today under the brand name Dolanit®10 and can be used in the most varied applications. The uses of the socalled technical fibres, which positively support the manufacturing processes of composites and the processibility and also influence the properties of solid materials positively, are wellknown since several years. Fibres have definite uses in the most varied branches of industry, either as supporting elements of the process or as reinforcing additives. Dolan GmbH manufactures acrylic fibres for PP compounds, concrete, mortar, friction linings and asphalt. According to the fibre specifications: e.g. strength, the modulus of elasticity, softening point, elongation etc., the fibres are aligned with the end product. Then, the fibres are processed further and offered with different cutting lengths and diameters. These fibres are available as a powder or pulp, whereby the fibre surface is opened up accordingly and a severalfold surface area is so provided in proportion with the weight. The newly developed Dolanit®18 fibres are acrylic fibres manufactured with chemical (polymerisation) and process-technical modification - drawing; heating; softening. These are specially meant for dry mortar mixtures, whereby the primary aim is correct mixing, without which the abovementioned features will not be possible.

The factory-made dry mortar is an important element in the new product Dolanit®18. Although this fibre already had very good properties, constant efforts were made to improve them further. Apart from the modification of the physical and chemical properties, the selection of the fibre content, the fineness and length of the fibre are extremely important factors for the dry mortar mixture and its composition. This article is based on mixtures of different products (that have been tested in practice) and their optimisation with the addition of different fibres having different diameters and fibre lengths. The results have been included in a thesis, which has been prepared at the Hochschule für Technik Regensburg on behalf of Dolan GmbH and which aims at defining the optimum fibre quality and fibre length for fibres used in dry mortar products. Apart from the properties of the solid material, the main focus was on the mixing in process of fibres and the resultant separation of the same.

2. POLYACRYLONITRILE FIBRES

2.1. General

Polyacrylonitrile fibres (PAN fibres) are high-quality plastic fibres with a modulus of elasticity of approx. 20 kN/mm² and tensile strength of up to 1000N/mm². The PAN fibres not only fulfil the general requirements, such as alkali resistance and rigidity, but also feature good bonding properties in the matrix. PAN fibres are mostly used as a replacement for asbestos in asbestos cement products, filigree concrete components, mortars, casts, asphalt etc. DOLANIT® fibres particularly have a kidney-shaped and round cross-section and a fine length structure. In the concrete, fibres having a length of 6 to 24 mm and a thickness of 0.05 to 0.10 mm are used. In mortars and casts, fibres having a length of 2.2 to 6 mm and a thickness of 0.014 to 0.5 mm are used.

2.2. Manufacture

Polyacrylonitrile fibres are spun from spinning material. The spinning material is manufactured with the process of polymerisation. The raw material, ACN [acrylonitrile] is the starting material. Individual molecules that form a double bond between two carbon atoms ($CH_2 = CH_2$) come together to form macro molecules. The fusion of molecules is triggered by the so-called catalysts, which ensure that the double bond between the two carbon atoms leads to a – CH_2 – CH_2 – fission. After this fission, the C atom excites another atom to open the bond. The – CH_2 – CH_2 groups fuse and the macro molecule is formed. This process continues till it is interrupted. This is achieved by using molecules, which do not excite other molecules to fuse together. In this way, the length of the macro molecules and thereby certain fibre properties can be regulated. The starting materials thus obtained are then processed to form fibres. By dissolving this material in a solvent, a semi-liquid mass is obtained, the polymer. To spin an endless fibre string from the polymer, the so-called wet spinning process is used for Dolanit®. In this process, spinning mass from the spinning nozzle is pressed in a precipitation bath, whereby the individual fibre filaments consolidate. The subsequent drawing and drying processes build up further fibre properties according to the final application.

3. PRODUCTS USED

3.1. Selected fibres

The following Dolanit®18 fibres on the basis of polyacrylonitrile were selected and tested for these test series:

Titer dtex	micros	2,2mm	4mm	6mm	8mm
1,9dtex	14,3	X	X	X	X
6,7dtex	26,8	X	X	X	X
16dtex	41,5	X	X	X	X
30dtex	57	O	X	X	X
60dtex	80	O	X	X	X

Table 1

4. TESTED DRY MORTAR PRODUCTS

4.1. General

Given below is an overview of the dry mortar products used in short [12]. Please refer to the technical leaflets in the Annex for detailed information.

1. [A] Light-weight plaster with lime-cement fibres MAP LF

MAP LF light-weight plaster with lime-cement fibres is a factory-made dry mortar made on lime-cement basis. A single layer of this product is applied as the first coat before mineralbound final coats and tiles. This product is particularly suitable for heat insulating walling material such as bricks, foam mortar etc. MAP LF can be used internally as well as externally.

2. [B] Light-weight flexible façade filler FSP-L

This product is used for the refurbishment of the inner and outer surfaces. FSP L can be used on all the stable old facades with mineral or plastic finishing coats. FSP L can be used as a pre-coat for the following finishing coats on well-bonding dispersion and silicate coats of paint. FSP L can be used in the dado region and also as a bonding mortar on XPS plates and as concrete for the subsequent plaster coatings.

3. [D] Adjustment of the timber floor board HDA

The HDA adjustment is made for: Smoothening, filling, balancing and levelling of wooden floor boards, parquets, particle boards V 100 and cement, anhydrite or melted asphalt floors or concrete floors before laying ceramic tiles or plates, PVC, wall-to-wall carpets. This application is possible in the inner and temporary wet areas.

4. Dispersion powder

Dispersion powder is an additive, which contains polymer particles. The addition of this powder improves the properties of cement and gypsum mortar. Addition of dispersion powder yields advantages while processing – need for less water and a longer processing time. Also, the bonding, flexibility, cohesion, elasticity and permeability properties improve. Because of these features, the dispersion powder is suitable for a number of applications e.g. in jointing compounds, façade coatings, tile adhesives, joint compounds and adhesives for plasterboards, lime plaster, adhesive mortar, mortar for brickwork etc. [13].

Product	Fibres in % over weight	In kg / Ton	Disp. Powder kg/Ton
(A) MAP-LF	0,04	0,4kg	
(B) FSP-L	0,04	0,4kg	
(C) KAM WN	0,06	0,6kg	20
(C) KAM WH	0,06	0,6kg	38,6
(D) FKW N	0,06	0,6kg	14,7
(D) FKW H	0,06	0,6kg	15,0
(E) HDA N	0,06	0,6kg	15,5
(E) HDA H	0,06	0,6kg	48,3

Table 2, Overview of the product

5. MIXING PROPERTIES OF THE FIBROUS MATERIAL

The laboratory mixer M-Tec as shown in Figure 1, is the basis for executing this test. A precise description of the test will be given later. In order to obtain results equivalent to FKM 1200 D, a ploughshare mixer was used here. This mixer has a gross volume of 15l and a net volume of 11l. The filling ratio recommended by the manufacturer lies between 25 and 75 %. The speed of the mixer varies from 40 – 230 U/min. The speed of the agitator (milling head) is 6000 U/min.

5.1. Description of the test

The dispersibility of the fibres was tested on mixtures of sand and binding agents, having a composition and apparent density similar to that of real products. According to EN1097- 3, the apparent density was determined for calculating the optimum filling quantity. Only rounded off figures were taken into account here. A filling ratio of 50% was selected, which is equivalent to 7.5 l. After this, the mass ratio of the fibres was calculated.

Figure 1, Laboratory mixer M-Tec

	Density in kg/m3	Mass [kg]	Fibre content [%.-Weight]	Fibre content[gr]
[A]MAP LF	**850**	**6,4**	**0,04**	**2,56**
[B]FSP L	**1200**	**9,0**	**0,04**	**3,60**
[C]HDA	**1300**	**10**	**0,06**	**6,00**

The dry mortar products were placed in a bucket and the fibres were placed in a small hollow and covered. The contents of the bucket were poured into the mixer from the top. The fibres were not separated before they were added in the mixer. The speed was set to 115 U/min for a one minute cycle. After one minute, the lid was opened and a visual check was conducted to see if the fibres had been mixed properly. This was repeated after every minute till a good result was obtained [in practice 1-4 min.] or till the five minutes mark was crossed. This mark was set to limit the time because a very long mixing period is not practical from the economic and logistic point of view.

Photograph 1– [E] FKE –Reference for Fibre clumbs fibre = 30dtex-6mm

Photograph 2, very good dispersion of fibres, in the HDA, Dolanit®18-1,9dtex-8mm

Photograph 3, fibre chips partly dispersed

5.2. Results, dry mixture

As mentioned before, fibre clumps are formed after a titre of >30 dtex [57µm]. This is because of the recipe, according to which the fibres have to be separated before they are added. Some manufacturers of mixers offer accessory devices, which help in loosening out the delivered goods so that no clumps are formed. According to the theory, an increasing fibre length and diameter hampers the distribution properties of the fibres. The fibres, which are 6mm in length, can be easily loosened and are still in use. Since the laboratory mixer operates with the same technology as the big mixer system, it can be assumed that the same results can be obtained here. If a mixer with another mixing technology is used, the results may vary, e.g. with respect to the mixing time, distribution and loosening of the chips. The results of the five tests were almost similar. The mixing time varied only slightly, by 2 to 3 minutes. Small fibre clumps were noticed in some places after a titre of 16 dtex. After 30 dtex, larger clumps were seen in every product. Longer the fibres, more difficult was the mixing process. Fibres having a cutting length of 2.2 mm and 4.0 mm did not create any problems. Starting from a length of 6.0 mm, it seemed difficult to separate the fibres completely from one another ("Chips"). In fibre lengths from 8.0 mm onwards, the formation of "chips" was more frequent. As mentioned before, fibre clumps are formed after a titre of >16 dtex. Some manufacturers of mixers offer auxiliary devices, which help in loosening the delivered goods so that no clumps are formed and fibre types with higher titres can also be processed. With increasing fibre length, the distribution properties of fibres deteriorate. As against fibre clumps as seen in the diagram Photograph 1– [E] FKE –Reference for Fibre clumbs fibre = 30dtex-6mm, fibre chips as seen in Photograph 3, fibre chips partly dispersed can be easily loosened and used further. Since the laboratory mixer operates with the same technology as the big mixer system, it can be assumed that the same results can be obtained here. If a mixer with another mixing technology is used, the results may vary, e.g. with respect to the mixing time, distribution and loosening of the chips

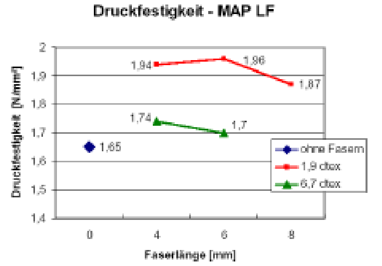
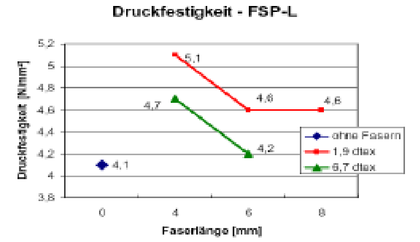
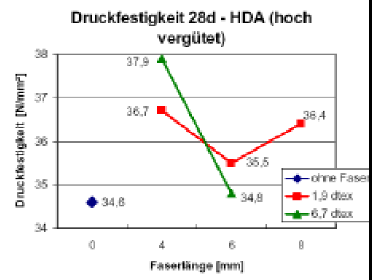
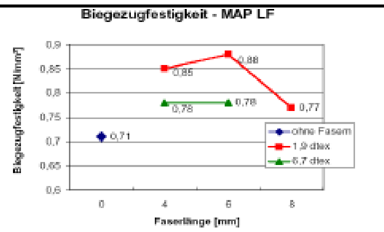
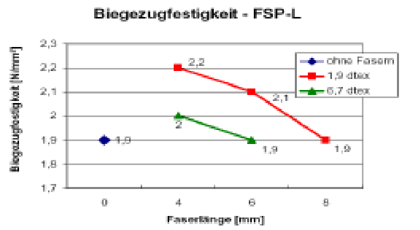
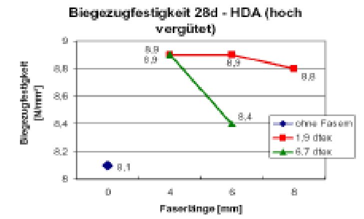
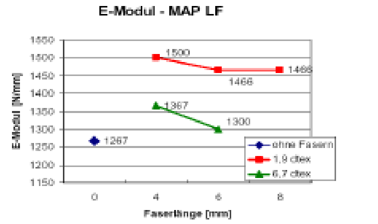
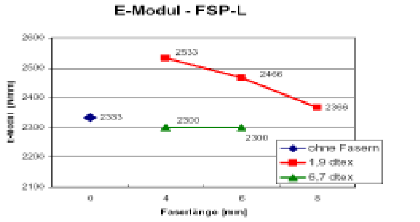
	Fibre [dtex]	Cut length in [mm]		
		4	6	8
HDA - Floor leveling mortar	1,9	No fibre clumbs Fibre well dispersed fibre clearly visual	No fibre clumbs Fibres entirely individualized fibre clearly visual	No fibre clumbs Fibres not entirely individualized Fibres clearly visual
	6,7	No fibre clumbs Fibre well dispersed fibre clearly visual	No fibre clumbs Fibres not entirely individualized fibre clearly visual	
	30	fibre clearly visual Big fibre clumps fibre good dispersed	Big fibre clumps fibre good dispersed fibre clearly visual	
	60	fibre clearly visual Big fibre clumps fibre good dispersed	Big fibre clumps fibre good dispersed fibre clearly visual	

Table 4 Results of dry mix, 2 ½ min. mixing time, fibre content 0,06% = 0,6kg/ton

	Fibre [dtex]	Cut length in [mm]		
		4	6	8
1)Facade render light 2)Light plaster, lime-cement	1,9	No fibre clumbs Fibre well dispersed fibre clearly visual	No fibre clumbs Fibres entirely individualized fibre clearly visual	No fibre clumbs Fibres not entirely indiv idualized Fibres clearly visual
	6,7	No fibre clumbs Fibre well dispersed fibre clearly visual	No fibre clumbs Fibres not entirely individualized fibre clearly visual	
	16	no fibre clumbs Fibre well dispersed fibre clearly visual		
	30	fibre clearly visual Big fibre clumps fibre good dispersed	Big fibre clumps fibre good dispersed fibre clearly visual	
	60	fibre clearly visual Big fibre clumps fibre good dispersed	Big fibre clumps fibre good dispersed fibre clearly visual	

Table 3, results of dry mixing, fibre content 0,06% = 0,6kg/ton

6. PROPERTIES OF FRESH MORTAR AND SOLID MATERIAL

	MAP – LF	FSP-L	HDA
Compression strength, blue no fibres, red 1,9dtexgreen 6,7dtex	 **Diagram 6** Translation: Druckfestigkeit – Compressive strength Ohne Fasern – Without fibres Faserlänge – Fibre length	 **Diagram 7** Translation: Druckfestigkeit – Compressive strength Ohne Fasern – Without fibres Faserlänge – Fibre length	 **Diagram 8** Translation: Druckfestigkeit – Compressive strength hoch vergütet – High-tempered Ohne Fasern – Without fibres Faserlänge – Fibre length
Bending tensile strength, blue no fibres, red 1,9dtexgreen 6,7dtex	 **Diagram 9** Translation: Biegezugfestigkeit – Bending tensile strength Ohne Fasern – Without fibres Faserlänge – Fibre length	 **Diagram 10** Translation: Biegezugfestigkeit – Bending tensile strength Ohne Fasern – Without fibres Faserlänge – Fibre length	 **Diagram 11** Translation: Biegezugfestigkeit – Bending tensile strength hoch vergütet – High-tempered Ohne Fasern – Without fibres Faserlänge – Fibre length
E-Modulus, blue no fibres red 1,9dtexgreen 6,7dtex	 **Diagram 12** Translation: E-Module – Modulus of elasticity Ohne Fasern – Without fibres Faserlänge – Fibre length	 **Diagram 13** Translation: E-Module – Modulus of elasticity Ohne Fasern – Without fibres Faserlänge – Fibre length	

6.1. Interpretation of the results

6.1.1. MAP – LF

No problems were faced as regards the processability; variations in the consistency test were less than 4% at an average. The fresh mortar density in all fibres showed an upward trend; the finer and longer the fibre, the greater was the difference. With the addition of fibres, the properties of the light-weight plaster with lime-cement fibres (MAP LF) improved. However, there was only a slight influence upon the adhesive pull strength. On the other hand, the compressive strength increased by nearly 20%, whereas the bending tensile strength increased by 25%. In both the situations, the 1.9dtex - 6 mm [4mm] fibres delivered the best results. The modulus of elasticity increased by nearly 20%. As mentioned before, there was hardly any improvement in the adhesive pull strength. However, in the 6.7dtex / 6 mm fibres, only a slightly improved result was seen. A cohesion fracture was noticed in all the cases (fracture pattern b). The fracture was in the mortar layer. The addition of fibres also had a positive effect on the apparent density. This shows that the 1.9dtex / 6 and 4 mm delivered the best results. To sum it up, we can say that the Dolanit®18- 1.9dtex / 4 mm and 6 mm fibres deliver the best results. Their values vary only slightly from one another. These fibres mix well and do not show any negative properties while processing.

6.1.2. FSP-L façade filler

There were no problems in the processibility. The spread value / slump changed according to the diameter of the fibres; the higher the fibre diameter and longer the fibre, the greater was its influence upon the spread value. The target value was 165 mm – 175mm. The fibre had a negligible influence on the density of fresh mortar. The number of air voids increased with the addition of the fibres; finer the fibre, higher the number of air voids and higher the fibre length, lesser the number of air voids. With the addition of fibres, the properties in almost all the areas improved. The compressive strength increased by nearly 25%, whereas the bending tensile strength increased by 17%. The modulus of elasticity showed an improvement in the value. In all the tests, it was clearly observed that the Dolanit®18 fibre with a titre of 1.9dtex and a length of 4 mm delivered the best results. As regards the adhesive pull strength, an improvement was observed only in the fibre 1.9dtex / 4 mm. The fibre did not have any effect on the adhesive pull strength test and its results. The addition of fibres had a positive effect on the apparent density; the 1.9dtex / 4 mm and 6.7dtex/ 4 mm fibres delivered the highest values. To sum it up, we can say that the fibre 1.9dtex / 4 mm delivered the best results. These fibres mix well and do not show any negative properties while processing.

6.1.3. HDA

The density of fresh mortar increases with the addition of fibres, irrespective of the fineness of the fibres and the fibre length. Immediately after 3 days, it is clear that the addition of fibres has a positive effect on the consistency of the mortar. After 28 days, the difference is more evident. The compressive strength [Diagram 5] and bending tensile strength [Diagram 1] show an improvement. In all the four cases (DF and BZ), the strength decreases with the increasing fibre length. The 1.9dtex / 4.0mm fibre prove to be the best fibre. The modulus of elasticity shows a slightly downward trend. Once again, the best values were delivered by the fibre 1.9dtex / 4.0mm. The apparent density clearly shows an improvement following the addition of fibres. In general, it can be said that the fibre 1.9dtex / 4.0mm is best suitable for this product.

7. LITERATURE REFERENCES:

The presented results are based on a thesis, which was prepared in cooperation with FHRegensburg, Sakret Rygol in Painten and Dolan GmbH in Kelheim. Our special thanks to the author, Mr. Florian Fleischmann