Investigations by Mehler on the PBO-Fiber Zylon® from Toyobo

The fiber Zylon® is probably known as today's strongest fiber that is commericially available. With a value of approx.37 cN/dtex its tensile strength is decidedly higher than those of the para-aramids (Kevlar® and Twaron®) and the high-performance polyethylene's (Dyneema® and Spectra®).

Chemical structure of ZYLON®

ZYLON® fiber properties

Type		Regular	High Modulus
		AS	HM
Filament decitex	dtex	1.7	1.7
Density	g/cm^3	1.54	1.56
Moisture Regain (65% RH)	%	2.0	0.6
Tensile Strength	cN/dtex	37	37
	GPa	5.8	5.8
	KSI	840	840
Tensile Modulus	cN/dtex	1150	1720
	GPa	180	270
	MSI	26	39
Elongation at Break	%	3.5	2.5
Melting Temperature	℃	none	none
Decomposition Temperature in Air	℃	650	650
Coefficient of Thermal Expansion	ppm/℃		-6
Limiting Oxygen Index		68	68
Dielectric Constant at 100kHz			3.0
Dissipation Factor			0.001

As soon as Zylon® -fibre became available in 1998 Mehler Vario System GmbH started with the initial weaving and treating of this product. Fortunately, the high strength of the fibre also lead to a high ballistic protective performance of the protective panels produced from the woven and treated fabrics.

Initial success

Mehler's first official testing certificate for armour panels constructed from fabrics woven from Zylon® yarns and combined with HPPE-UD-shield materials supplied by DSM was to German Shoot Class 1. This certification was obtained at the Beschußamt Mellrichstadt in 1999, the weight of the certified armour being weight only 4,3 kg/sqm – at that time the lightest armour solution available.

In the following years Mehler's research and development of Zylon® based armours has been continuing, leading to further reduction in the areal weights. Weights of less than 4 kg/sqm fabric only solutions and 3,6 kg/sqm for Zylon®-shield solutions became possible and were certified for German Shoot Class 1. These low weights were not achievable with the traditional para-aramid fabrics or HPPE.

The new opportunities as well as the request for permanently wearable, lightweight and comfortable vests, soon lead to the demand for a maximum areal density of 4 kg/sqm for German Class 1. This being apparently possible following the early certified test results. The Bundesländer Bavaria, Northrhine-Westfalia, Rheinland-Pfalz and Schleswig-Holstein restricted their tenders with this demand to the only possible solution – the use of Zylon® in their vests.

Mehler initially participated in these tenders, which in the cases of Bavaria and Northrhine-Westfalia included an extensive wearer trial.

Initial indications of a potential problem

During Mehler's continuous research and development programme for this new but as yet un-proven high-performance fibre with regard to time/performance, a potential problem with hydrolysis that reduced the tensile strength and hence the ballistic performance fibre was discovered. (Hydrolysis is the breakdown of a chemical structure by the action of moisture and is not reversible).

In order to obtain short-term results for the long-term behaviour of this material, so-called ageing-tests were conducted. These tests involved the increase in temperature and relative humidity over and above what would be normal for the fibre to experience in its expected working environment. In this way the ageing process of the fibre is accelerated. Without this kind of acceleration the alternative would be to start using the material and hope that there would be no reduction of performance with respect to time. The Technical Requirement for Ballistic Protective Vests in Germany, demands that the protection performance of body armour produced from already time proven materials must be 10 years without any reduction, and for new un-proven materials such as Zylon® the demand is for 5 years without any reduction in protection performance.

In the course of normal routine ageing tests at DSM – the only supplier of UD-shield including Zylon®-fibre at that time, it was found, that the ballistic protective performance of the protective panels dropped after a short period of exposure to temperatures of 60°C and 80°C and a relative humidity of 80% in a way it was not seen with normal HPPE or Aramid panels before.

Initial suspicions that it was the shield matrix that was the cause of this hydrolysis proved to be unfounded as further tests conducted on the fibre itself showed a very similar problem.

Concerned by their initial test results and those of DSM, Mehler in the middle of 2001 withdrew their tender offers that included armour containing Zylon® fibre and stopped offering vests made from Zylon® fibre for the time being. Providing customers with armour with a reliable protective performance over the expected 5-10 year term, could not be guaranteed following the initial ageing tests results.

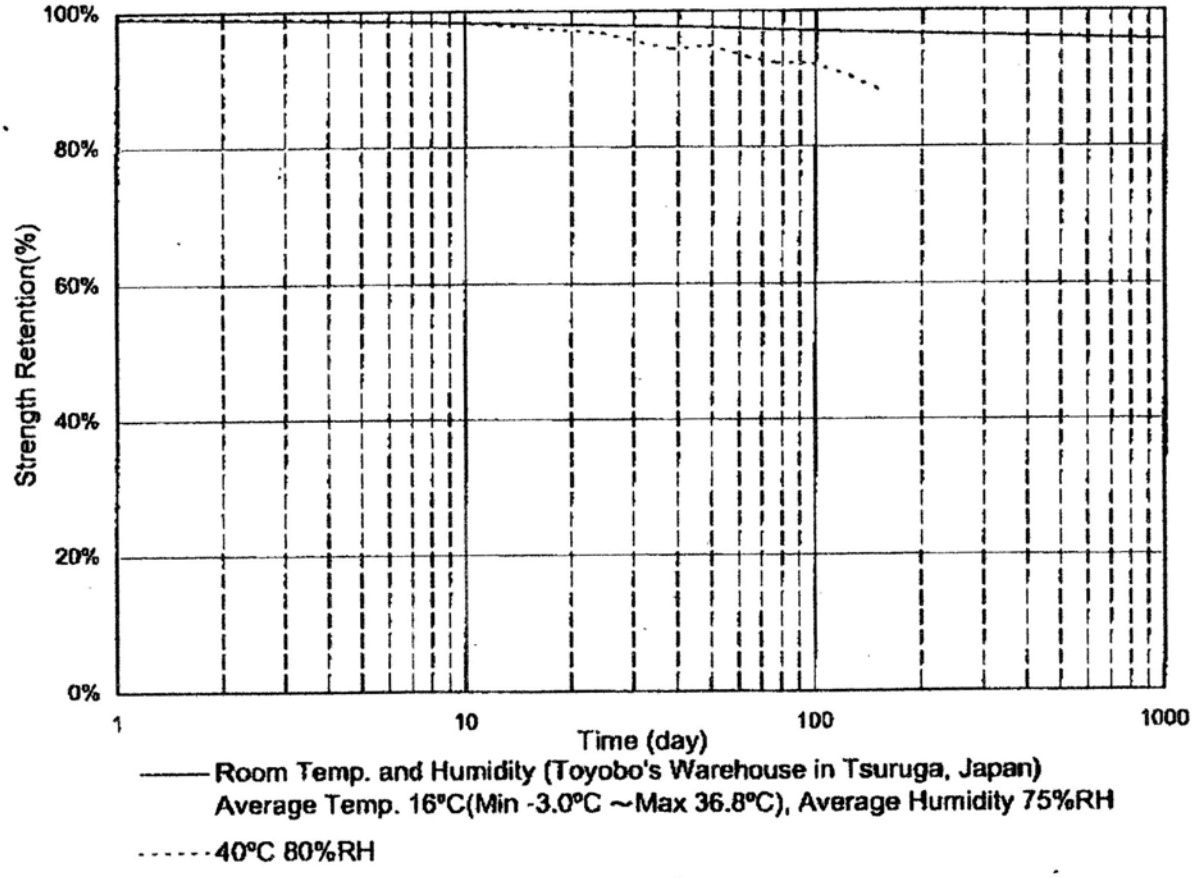
In the second half of 2001 Mehler started its own evaluation of protective armour panels based on Zylon® fibre. Apart from trying to prove or disprove the effect of hydrolysis on a real time basis, we are also looking into potential solutions in the processing of the fibre, which may restrict or even avoid the decrease in performance due to hydrolysis of this exciting new fibre.

Ballistic tests (V50-method), as well as the ageing procedure were done neutrally at the Beschußamt in Mellrichstadt. Evaluations concerning the moisture content of the test panels, the partial and complete de-hydration of some of the panels as well as the controlled encapsulation in water- and vapour-proof covers were done at the Fraunhofer Institute.

The completed tests, more or less showed similar results as were indicated by DSM's evaluation and our own ballistic test results. The ageing conditions were a temperature of 70°C and a relative humidity of 80%. The noted drop in ballistic performance (V50-method) after the 8 weeks was in excess of 15% for most of the tested panels. Of particular importance was the fact that even the fully water and vapour-proof encapsulated panel, which was sealed in under normal ambient conditions, showed similar decrease in ballistic performance. This could indicate, that the normal moisture content in the fibre which is about 2%, could cause hydrolysis without the need for exposure to additional moisture.

At the same time as our findings the producer of the fibre – Toyobo – started ageing tests. The initial tests at temperatures of 60° and 80°C and a relative humidity of 80% also showed a rather quick decrease in the tensile strength. With the assumption, that it probably needs high temperatures to initiate a hydrolysis effect and the fact, that these temperatures will hardly occur in the real body armour use, new tests were started at 40°C.
A temperature of 40°C is very close to the normal wearing conditions, as amongst others a study "Evaluation on the thermo-physiological effect of wearing body-armour" of the Institute for physiology at work at the university in Dortmund has shown.

Toyobo's results so far show a reduction in strength of more than 10% after approx. 150 days (see graph below, issued April 1st 2002). The evaluation will be continued and we promised an up-date every 3 months.



How can the above results from the ageing test be transformed into practice?

There is no easy answer to this question. Many parameters may have an influence in practice. What the ageing test showed is – that under the influence of normal wearing temperature and relative humidity **Zylon®** fibre does reduce its strength at a remarkably higher rate than well-established materials for body armour such as para -aramid and HPPE. How and in what time frame this may lead into a failure in the required level of ballistic protection finally can only be answered by practical test.

Mehler Vario System GmbH started its own practical test with employees from administration and production wearing ballistic protective vests made from **Zylon®** fibre. The wearer trial now will continue for several months. All relevant parameters (the daily wearing time, the surrounding temperature, clothing used underneath or on top of the body-armour, the moisture pick up of the individual elements of the vest, etc.) will be documented. For every vest being worn in this test an identical insert has been produced from the same material batch and was tested ballistically (V50-method) before the test began. Identical tests will be repeated after at least 6 months of continuous wear on some of these vests. Depending on the results, the wearer trial will be continued for a further period when further ballistic tests will be carried out on the remaining vests.

The protective inserts chosen for these tests are all of an identical construction and have an areal density in the region of 4kg/sqm. The form of encapsulation does differ from vest to vest in order to evaluate whether different water and vapour permeable covers may have an influence on the hydrolysis effect and possibly reduce or even avoid the drop in performance seen on the ageing tests.

We will inform you about our findings on this website, once we have new information or when our evaluation is completed.

S.Will, 05.07.2002