Correlating Structure Property Relationship of Kevlars by Scattering and Birefringence

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Abstract- Brand of para-aramid fiber, patented by DuPont called Kevlar. According to Mulkern and Raftenberg, “This material has a high strength (several times stronger than steel)” (2002, 13). For the first time Kevlar was obtained in 1964 by the research team Stephanie Kwolek (Hancox, 1993, 312). A production technology has been finalized a year later. However, commercial production of Kevlar began only in 1970 (Chaos.org.uk, 2015). The high *strength* and good *thermal properties* are the two most important qualities that are characteristic for Kevlar fibres (Brody, 1994, 113). The study of synthetic fiber’s features such as Kevlar is a very important practice today. Therefore, this work has relevance to modern scientific base.

This paper focuses on research of structure and certain features of the Kevlar 29 and Kevlar 49. Especially, it is considered certain properties by *birefringence* and *scattering* (Toennies, 1973, 129). In the first part of paper, the author will consider the basic information about Kevlar 29 and Kevlar 49 for a better understanding of the research subject. Next, it will be introduced information about structure’s and other features of these materials. The next part of this paper will be considered two types of processes that can be applied to such types of materials as Kevlar 29 and Kevlar 49. This is especially considered mechanical, thermal and electrical-light properties of this type of fiber. The work uses a wide range of sources. First of all these are scientific works of various scholars from around the world which are more or less available to students. It also uses all available official information on the matter and objects that are considered in the work.

Index Terms- Birefringence, Property, Scattering, Structure

I. INTRODUCTION

In the history of the wars most pressing question was the protection of life soldier. Steel armour, leather jackets - all at once it became archaism after the invention of firearms. The world began to look for weapons workshops materials that could have an impact, or at least reduce the deadly effect of bullets and shells. The problem was that traditional steel plates were too heavy and inefficient (Vriens, 1968, 49). The emergence of new plastic materials has become almost a panacea for seemingly stalled development of passive protection. But the developers had to search long before it was matched the perfect composition and technology of producing over impact-resistant plastic. The problem was solved due the para-aramid yarn (Kevlar para-aramid pulp, 1991,7). “Composite materials are defined as a combination of two or more materials that have quite different properties, which offer more desirable and unique properties than the individual materials. As a result, it can also be noted that the combination of materials do not dissolve or blend into each other, and the theory behind the construction of composite materials comes from the need to create strong, stiff, and light materials. Materials such as glass, carbon and Kevlar have extremely high tensile and compressive strength, but in solid form, many random surface flaws are present in such materials, which cause them to crack and fail at a much lower stress than it theoretically should. Fiber–reinforced composite materials are continuing to replace the conventional metals in primary and secondary aerospace and aircraft structural elements owing to their superior mechanical properties such as high strength–to–weight stiffness–to– weight ratios.” (Abu Talib et al., 2011, 1) In 1965, DuPont scientists developed a new method (for the production of almost perfect polymer chain length) (DuPont ups US Kevlar production, 2001, 14). According to Lewis, “Polymer was obtained in the form of a liquid crystal solution, due to the simple repetition of molecular structures”(Lewis, 1999, 68). The key structural requirement for basis consisted in the fact that oriented in the position of the benzene ring in the rod was formed the molecular structure. This development is further embodied in the creation of fibre Kevlar (Technologystudent.com, 2015). Hodgson noticed, that “If it is considered stiff-molecules, there are rod-like molecules, they represent a well formed oriented chains in the diluted solution and at a high concentration their shape does not change” (Hodgson, 1963, 71). Then, when it is applied to the solution of shear stress, it is forms oriented molecular structure of which is shown in Fig. 1.

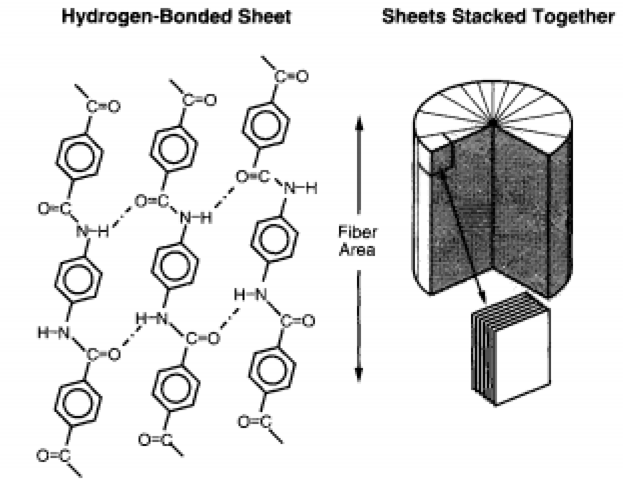

Figure 1: Rod-like fiber structure by the radial stacking of hydrogen-bonded sheets. (Dupont.com, n.d., 4)

The fibril structure of Kevlar has been suggested by Panar et al., as being shown on Figure 2, where ripped end of a PPTA fiber is visible (1983).

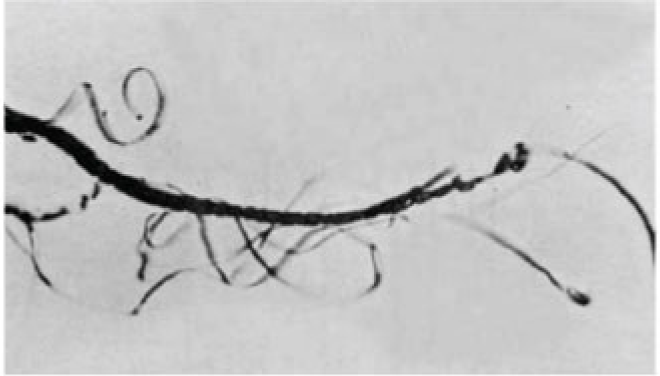

Figure 2: Bundles of PPTA fibrils

Surface of a PPTA fiber is shown of Figure 3 (A), the image has been obtained using transmission electron microscope (TEM). The fibrils are approximately 600 nm wide and several centimetres long (Panar et al., 1983). Skin-core structure of etched PPTA fibers can be seen on Figure 3 (B). The image has been created by scanning electron microscope (SEM), with ends of the fiber cut using plasma technique to study skin-core structure of the fibre. These images shown to Panar et al. that while skin fibres are perfectly oriented, core ones are imperfectly packed inside the fiber (1983).

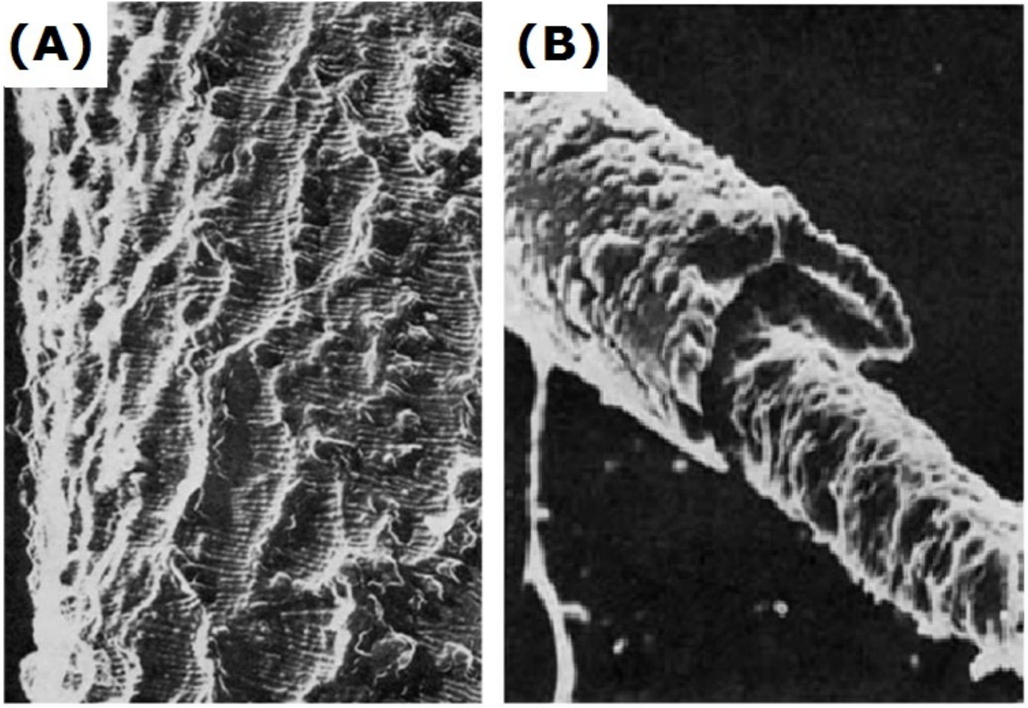

Figure 3: (A) The etched surface of PPTA fiber by TEM. (B) Skin-core structure of PPTA fibers by SEM (Panar et al., 1983).

II. .METHODOLOGY

“There are several different grades of Kevlar, but the most common types of Kevlar are Kevlar 49 (composites grade) and Kevlar 29 (ballistics grade). Fibre Glast only carries Kevlar 49 fabrics. These fabrics are developed specifically for composite reinforcement. They can be used with Epoxy, Vinyl Ester or Polyester Resins to create a rigid laminate.” (Fibre Glast Blog, 2013)

For these work it can be used any Kevlar sample. Since this material is actively used for over 30 years, it is no problem to find or buy a pattern of a certain type of fibers of the finished product (helmet, body armour and so on). To begin, it is necessary to understand the basic principles of research. Since it is a popular method of structure research and materials’ properties, it is necessary to consider the case and noted some already known results. It uses a large set of resources that include books, scientific articles and so on.

In general, the birefringence is the effect of splitting the light beam into two components in anisotropic media. It was first discovered by Danish scientist Rasmus Bartholin in the crystal of Iceland spar. If the light beam is incident perpendicularly to the crystal surface, this surface it splits into two beams (Fewster, 2003, 40). The first beam continues to spread directly and called ordinary (o), the second is deflected to the side, and is called extraordinary (e). “Birefringence (double refraction) of a fibre is the difference between the refractive index of the fibre along its axis and across the fibre axis.” (Abu Talib et al., 2011, 3) The method of stress strain measurement for characterization of synthetic fibers is a well known technique. Fibers with a high tensile modulus can be classified as high performance fiber. In considering the stress-strain curve of Kevlar 49, it is clear that there is linear relationship indicates that the behavior of the material (in general elastic behavior) on not big extensions. As a result, it can be concluded that since Kevlar has sufficient specific strength (ratio of the strength to specific gravity) (Mechanical properties of hybrid, 1988, 80), this material is quite unfit for use as reinforcement for composite materials. This method is particularly useful in those cases where the robot is carried out with Kevlar par amid fiber. The main feature of these fibers is that they provide high modulus and high strength (Ericksen, 1979, 227). This is possible due to the highly oriented, highly crystalline structure of the solid chain. Despite the fact that it is fairly easy to measure the stress-strain behavior of Kevlar fibers, however birefringence of such materials is too high to be measured by ordinary methods (Lee, 1989, 201). “The value of optic birefringence for Kevlar 29 fiber is 0.625 and that for Kevlar 49 fiber, 0.662; the form birefringence correction was not reported in either case. Due to the presence of radial structure, Kevlar also exhibits lateral birefringence in the range of 0.022-0.065 (McIntyre, 2005, 31). Strain birefringence has also been reported in Kevlar and it has been concluded that birefringence increases with strain even at relatively constant fibre modulus” (Kumar, 1990, 53).

In generally, scattering of particles that change of the motion direction of the particles resulting from collisions with other particles (Cohen et.al., 1992, 43). Quantitatively, the scattering is characterized by effective cross-section (Barakat and Hamza, 1990, 90). This is usually considered a common experimental situation, when the particle hits the other particle (target), which can be considered fixed. After the collision, the particle changes its direction of motion, and the target particle is experiencing the impact. The system of reference in which the target is fixed, called the lab. Theoretically, it is more convenient to consider the scattering in the frame center of inertia, limited relative motion of the particles (Udd, 1992, 331). For example, in the case of two-particle scattering in the centre of mass scattering problem is reduced to a single particle with the reduced mass on a stationary target. One of the parts of nuclear physics and particle physics is a specific theory which is based on elastic scattering. This process is characterized by the fact that the kinetic energy of the particles is always saved if the point belongs to the particle point of the center of mass frame (Toennies, 1973, 129). However there is one nuance, the direction of this propagation is changed. Also it should be noted that the processes of scattering processes usually are explained process for which the total kinetic energy of the system will remain.

In the case of Kevlar there are many methods. Apparent crystallite size in Kevlar is 6.5, 5.3> 10.9 nm measure from (110), (200) and (006) reflections respective using wide angle X-ray scattering (WAXS). Based primarily on electron microscopy observation and peeled sections of Kevlar, it was concluded that the super molecular structure has radically oriented crystallites. This fibre is also characterized by pleated structure being about 170 and it overall fibre structure being fibrillar” (Kumar, 1990, 52). These findings only reaffirm sufficient specificity of Kevlar as usefulness composite many goals material. That is why such research is very important.

Diffractogram of the Figure 4 was obtained from Kevlar fiber with a 3 mm 16 diameter X-ray beam at the ESRF (European Synchrotron Radiation Facility) synchrotron source.

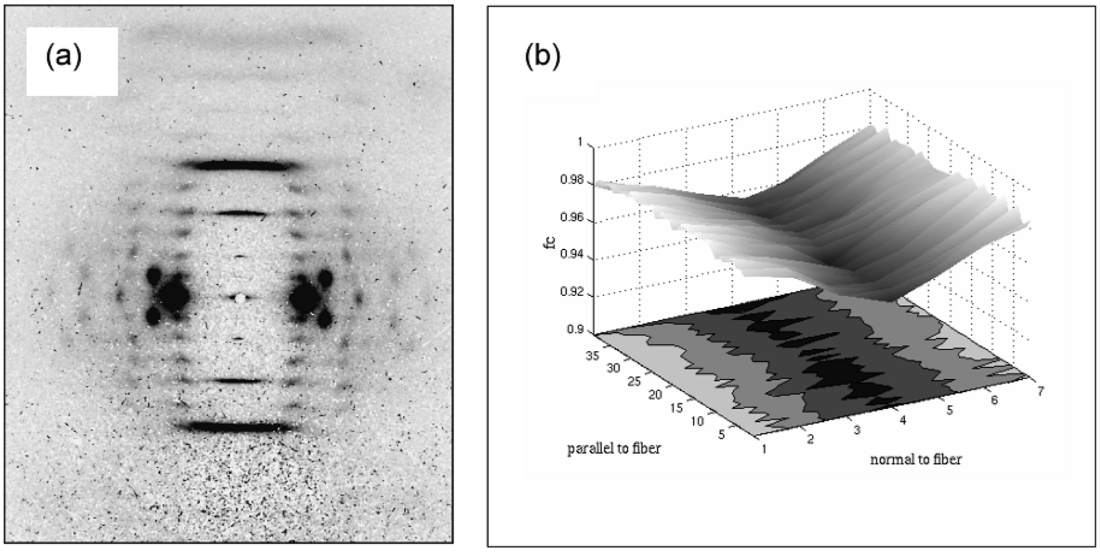

Figure 4: Wide-angle X-ray diffraction data from a Kevlar fiber using 3 mm diameter beam (λ 0.08 nm). (b) Plot of the Herman’s orientation function (Murthy, 2004).

Hindeleh and Abdo (1989) reported that “the angular range of the diffraction angle 2θ of the peaks of the (110) and the (200) reflection-planes is 12-35°”, and after 35° the scan gave flat intensity curves (Ahmed, 2014). Figure 5 illustrates the WAXD patterns of the equatorial and meridional scan of Kevlar 29 and Kevlar 49 fibres.

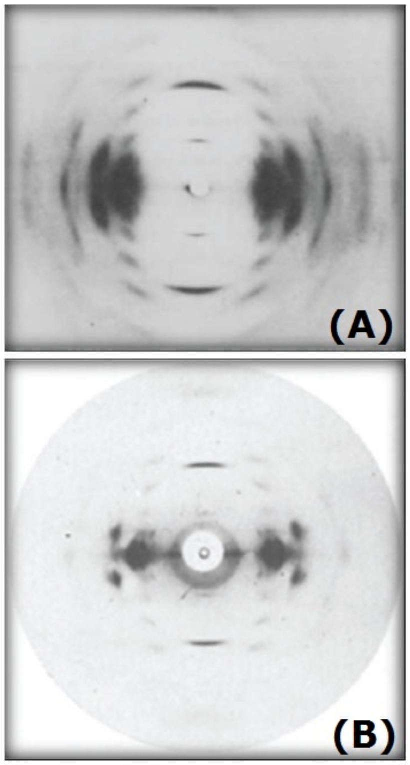

Figure 5: WAXD patterns of Kevlar fibres for (A) Kevlar 29, and (B) Kevlar 49.

III. RESULTS

Depending on the process conditions the hood, it is possible to obtain two basic types of fiber Kevlar - a material with high modulus of elasticity and a smaller elongation, or a material with a large elongation and a lower modulus. These materials have received trademark Kevlar 29 and Kevlar 49. Table 1 shows the properties of all types of these two types of fibres. As already noted, the main difference is the modulus of elasticity and elongation at break. Kevlar 29 has an elongation at break of 3.6% vs. 2.4% for the Kevlar 49, and on the modulus of elasticity of Kevlar 49 almost 30% higher than Kevlar 29. Besides factor of depending on the strength of the fiber twist it can be considered in detail the effect of the number additions of the threads during the formation of Kevlar cord on his strength. High level Kevlar properties observed not only at high temperatures but also at low arctic temperatures. At a temperature of -46 ° C the strength does not change, modulus increases slightly, lengthening also does not change, both along and across the fibers. Thus, the data show high performance Kevlar fibers not only at high but also at low temperatures, which has significant practical importance.

Properties	Unit	Kevlar 29	Kevlar 49
Type	denier (dtex)	1500 (1670)	1140 (1270)
Density		1.44	1.44
Breaking Strength	N	338	264
Breaking Tenacity	MPa	2920	3000
Tensile Modulus	MPa	70500	112400
Elongation at Break	%	3.6	2.4

Table1: Some mechanical properties of Kevlar 29 and Kevlar 49. (Dupont.com, n.d. 9)

The polymer chains orientation is much more perfect in Kevlar 49 than in Kevlar 29. The reason for this is the fact that Kevlar 49 is made by the heat treating process of dried Kevlar 29 under tension at high temperature, hence passage of the water molecules is much smaller in Kevlar 49 (Ahmed, 2014).

The most important characteristic of the strength properties of the Kevlar fibers is depending of the strength fiber on the exposure time at various temperatures. These data are shown in Fig. 6. As can be seen from the figure, at temperatures up to 155 ° C, the strength of Kevlar fiber varies little (3-4%). When the temperature rises to 175 ° C, change in strength for 125 decreases almost 3 times. The temperature of 245 ° C is critical at this temperature Kevlar fiber can be exhibited only for 25 hours with a decrease in the strength of 2-2.5. Thus, it is seen that in the temperature range up to 195 ° C Kevlar fiber effectively preserves the strength properties for a long time.

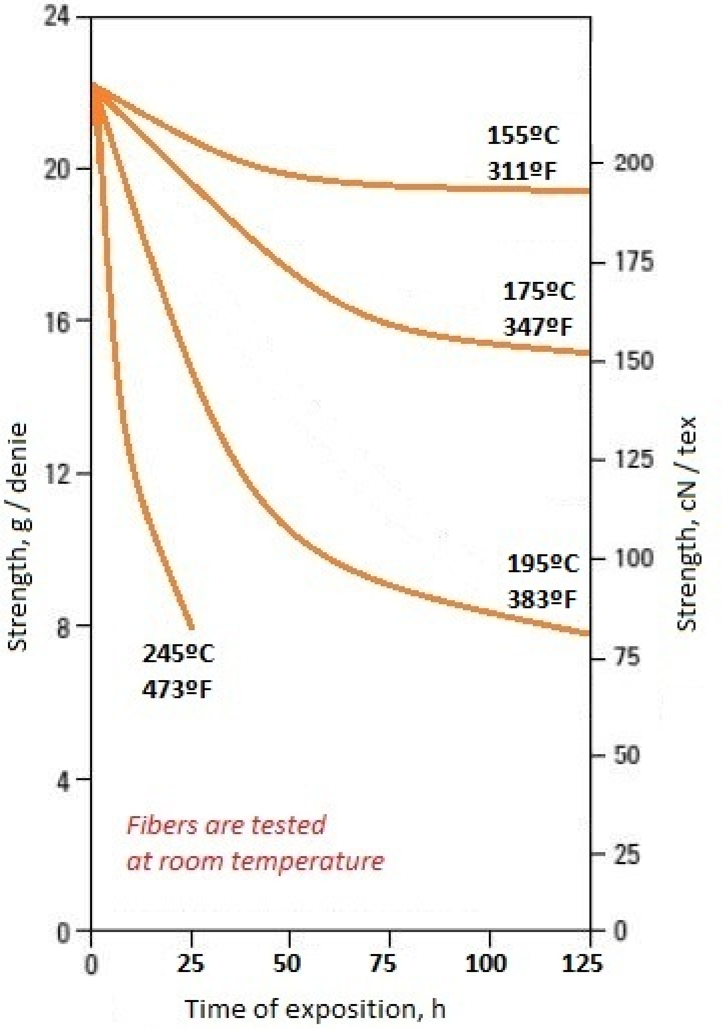

Figure 6: Kevlar fiber strength as a function of dwell time at different temperatures.

Figure 7 shows stress–strain curves and plot of relationship between strain and loss factor of Kevlar 49.

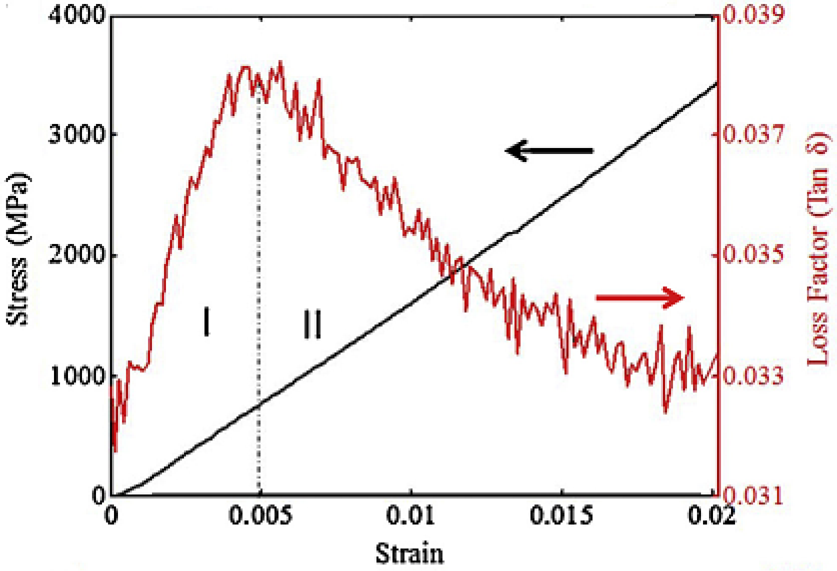

Figure 7: Plot of stress and loss factor versus strain in Kevlar 49, shown up to a failure strain of 0.02 (Raja et al., 2014).

Table 2 summarizes the hydrolytic stability of fibers Kevlar for exposures up to 40 hours. It was shown that in these cases, the strength is retained more than 80%.

Exposition, hours	Retention strength,%
0	100
20	96
40	91

Table 2: The hydrolytic stability of the fiber Kevlar

The most important issue of stability to external influences Kevlar is its interaction with ultraviolet radiation. Figure 8 shows the absorption spectra of Kevlar fiber of radiation from sunlight. It can be seen that there is an overlapping zone with a wavelength of 300 to 480 nm, wherein the active Kevlar absorbs ultraviolet radiation of the solar spectrum.

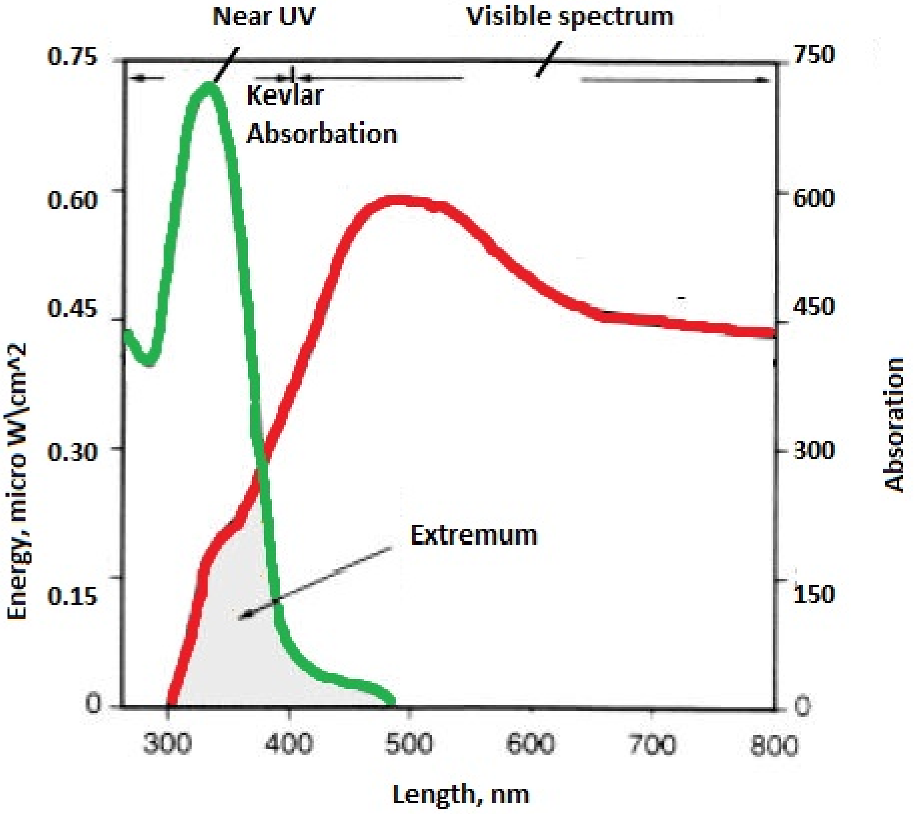

Figure 8.: Aliasing of the Kevlar fiber absorption and sunlight

IV. DISCUSSION AND CONCLUSIONS

From the preceding paragraphs it is clear that these two types of Kevlar – Kevlar 29 and Kevlar 49 have some similar properties and at the same time very different. The comparison shows that Kevlar fiber is less durable than glass fibers and there is at high of carbon fibers in this context. On the other hand, its modulus of elasticity even surpasses the glass fibers, and there is close to a high strength polyethylene. Certainly almost twice yield carbon fiber and steel wire. With regard to the elongation at break, Kevlar fibers are on one level with high strength polyethylene, steel wire, and significantly higher than the carbon fiber. Polyamide and polyester yarns are strongest than Kevlar. Data show that the Kevlar fibers are very high-tech and provide a high level of workability of the polymer fibers.

In conclusion it is worth say that materials such as Kevlar 29 and Kevlar 49 are quite complex composites. Despite the fact that their active use began in the 70s of the last century, and now they still remain relevant materials for integrated research. Such techniques as scattering and birefringence are powerful mechanisms for research and not only mechanical properties of various kinds of materials, including for Kevlar. That is why, active using of such techniques is very important for understanding of nature.

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