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STRATEGIC STUDY, TESTING AND ANALYSIS OF SILK FIBER AS OPTIMIZED APPLICATION IN BULLET PROOFING TECHNOLOGY

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ABSTRACT
Nowadays technology has become more challenging in different fields of engineering and the research is carried out on some traditional natural polymers such as silk. Sericulture or silk production has a vast and colorful history unknown to most of the population. For centuries the West knew very little about silk and the people who made it. For more than two thousand years the Chinese kept the secret of silk altogether to themselves. It was the most zealously guarded secret in history. According to Chinese tradition, the history of silk begins in the 27th century BC. Its use was confined to China until the Silk Road opened at some point during the latter half of the first millennium BC. There have been lot of studies dealing with the chemical properties of silk but this report is targeted towards strategic study, testing and analysis of silk fiber and fabric with respect to their mechanical and physiological properties. With the use of non-renewable resources getting limited every day, it's the high time that supplementary raw materials need to be looked upon and analyzed so as to replace the resources whose extinction is inevitable. Silkworm silk and spider silk have been researched hugely in order to substitute man made materials which are on the verge of getting exhausted. Needs of we human beings are infinite and the resources are limited, so I in the assistance of my respected and co-operative mentor have worked in a direction making sure the human needs remain fulfilled. With this approach, few tests such as linear density and tensile strength (tenacity, breaking load, elongation) have been performed on raw tussah silk multivoltine fiber and the reports are analyzed thoroughly to give its optimized application in bullet proofing technology. Application of silk in bullet proofing technology is still just a potential use of silk, but apart from that silk is used in many fields such as tyre technology, parachute making, comforter filling, artillery gunpowder bags and tremendously in medical field. Not to forget its tremendous application in textile industry!

KEYWORDS: Tussah silk, multivoltine, linear density, tensile strength, tenacity, breaking load, elongation, optimized application, bullet proofing, silk fiber, technology.

INTRODUCTION
Cocoon shells which are produced by silkworm caterpillars are one of the natural structures and polymeric composite materials which exhibit excellent mechanical properties. Silkworm eats mulberry leaves for almost 5-6 weeks with the purpose of storing enough nutrients and becoming capable of shedding their skin for almost five times. By doing this silkworm larvae start constructing protective cocoons on their pupas. This cocoon protects the moth pupa against microbial degradation and desiccation during metamorphosis, and also protects against potential predators. A silkworm caterpillar spins a lightweight and compact cocoon around itself by continuously moving its head in the shape an S and by bending and stretching its body in a cyclic manner. This process of construction of a cocoon requires approximately 3 days. After it has finished spinning the cocoon, the silkworm sheds its skin for the last time and becomes a pupa. The silken cocoon shell is comfortable and protective, allowing the pupa in it to evolve into a silkworm moth. The ellipsoidal cocoon has the smallest thickness at its two ends so that the moth can break through it after the metamorphosis from pupa to moth. The cocoon has lot of wrinkles on its outer most surfaces that are formed due to its non-uniform shrinking during the drying process[1-8]. A cocoon is a natural polymeric composite shell made of a single continuous silk strand with a length in the range of 1000– 1500 m and conglutinated by sericin. The raw silk which comprises the cocoon consists of mainly two proteins, sericin and fibroin. Sericin is soluble in hot water, while the fibroin is not, Because of their extraordinary mechanical properties such as Young's modulus and strength, natural silk fibers produced by silkworms, spiders and hornets have attracted tremendous attention in the past decade. Studies on the relationship between their macroscopic properties and multiscale micro- and nano-structures seem to be of especially great interest, as a means to design and fabricate advanced biomimetic materials. Van der Kloot and Williams studied the spinning process of silkworms under different conditions; for instance, by changing the spinning platform, considering the carbon monoxide and carbon dioxide's effect, and varying chemical and surgical procedures. Kaise and co-workers suggested some

computational models for simulating the movement pattern of a larva head and the stretching, bending and swinging of its body to form a cocoon. Using optoelectronic methods, Musayev examined some technological parameters of cocoons, *e.g.* spectrum characteristics describing cocoon shell's absorption and reflection of light in various wavelengths. Using thermo gravimetry, differential thermal analysis and Fourier transform infrared absorption spectrometry; Zhang *et al.* [21] studied the color, size, and shape of *Bombyx mori* cocoon shells after heat treatment at increasing temperatures. It was found that the size decreased with an increase in temperature and weight was lost from the cocoon shell. Tsukada *et al.* [13] studied the thermal decomposition behavior of sericin cocoons and structural changes of silk fibers induced by heat treatment. Cocoon shells play a significant role in the transformation from silkworm and pupa to adult moth [9-15].

Investigations on the physical and mechanical properties of these kind of natural polymer composite materials will be of particular significance to gain a deeper understanding of the possible applications of various natural polymers like silkworm silk and spider silk. With advancement in technology and modification in structure, these super polymers can possibly be created artificially and that can act as a boon to the mankind if done successfully. A possible use of silk and spider fiber is in the field of bullet proofing.

To date, however, there is a surprising lack of research on the mechanical properties and microstructures of natural silk fibers. The present paper is aimed mainly at systematic experimental investigations of natural silk fabric and fibers.

Silk fiber or any other natural fiber is perhaps the most underrated material available and with increasing deficiency of manmade and non renewable resources, these fibers and fabrics will be most valuable material in the coming years. There are uncountable applications of silk apart from being a raw material for clothes and lingerie, upholstery, wall coverings, window treatments (if blended with another fiber), rugs, bedding and wall hangings. However, with upcoming advancements in industrial technology, silk finds many industrial uses as well like parachutes, bicycle tires, comforter filling and artillery gunpowder bags.

MATERIALS & METHODOLOGY

One M V raw silk (small skeins) was taken as the sample to test its linear density and tensile strength. The testing process was successfully performed in Central Silk Technology Research Institute, Central Silk Board, Bangalore.

Linear Density

ASTM D 1907:07 was taken as the criteria for testing linear density of the silk sample. Initially one skein from each package in the laboratory sample was selected. It was then subjected to pre conditioning and conditioning subsequently. Pre conditioning skeins of the as received yarn was carried out in an atmosphere that does not exceeded a temperature of 50°C (122°F), and the relative humidity was maintained between 10 and 25 %. Importantly pre conditioning was carried out in an oven. After pre conditioning the sample was subjected to conditioning process which was carried out in a standard atmosphere for testing textiles, *i.e*., 21 ± 1°C (70 ± 2°F) and 65 ±2% relative humidity, till the moisture equilibrium was reached, that is, till the mass of the specimen was increased by more than 0.1 % after 2 h in that atmosphere. After pre conditioning and conditioning, weighing process of the conditioned sample was carried upon. All the skeins were weighed together at every step, even though, they were weighed separately earlier. From weight of whole sample total mass of all the skeins were obtained and from total mass average mass of a single skein (M) was calculated. Length (L) of the sample was read from the skein gage.

General Equation for Yarn Linear Density (D) = (M/L) × (A/B)

TABLE 1: Table I- Constants A and B for different linear density units to be used in General Equation for yarn density

Length of skein in:		Meters	Yards	Yards
Mass of skein in:		Grams	Grams	Grains
Tex	A/B	1000/1 = 1000	1094/1 = 1094	1094/15.43 = 70.86
Deniar	A/B	9000/1 = 9000	9842/1 = 9842	9842/15.43 = 637.8
Spyndle	A/B	13167/453.6 = 29.03	14400/453 6 = 31.75	14400/453.6 = 2.057

Tensile strength

Normally, tenacity and is carried out on the serigraph strength tester or the serimeter. But CSTRI has installed uster dynamat II, which is a single thread strength tester working on the principle of constant rate of loading. The tester works on the principle of constant rate of traverse pendulum type of yarn strength testing machine, graduated in grams and capable of recording simultaneously the breaking load and the corresponding elongation of the threads.

Prior to the test, the test sample was conditioned in standard atmospheric conditions. The apparatus was calibrated according to the guidelines. The distance between upper and lower clamps was fixed at 10 cm. the traverse speed of the lower clamp was 15 cm per minute.

The den of each skein was already determined in the previous test. Here, in this step we tested the sample for its tenacity and elongation by uster dynamat II. The breaking load in grams and elongation of the test skein was noted as recorded on the machine.

Tenacity in terms of gf/den was calculated by the following formula:

Tenacity in gf per denier, $t = \frac{z}{d}$

Where, Z= breaking load in g of test skein

d= denier of test skein

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FIGURE 1: Tussah silk fiber

FIGURE II: Fiber testing of tussah silk fiber under process at CSTRI, Bangalore.

FIGURE III: A picture of Uster Dynamat II. The machine used at CSTRI for testing of silk for its tenacity and elongation.

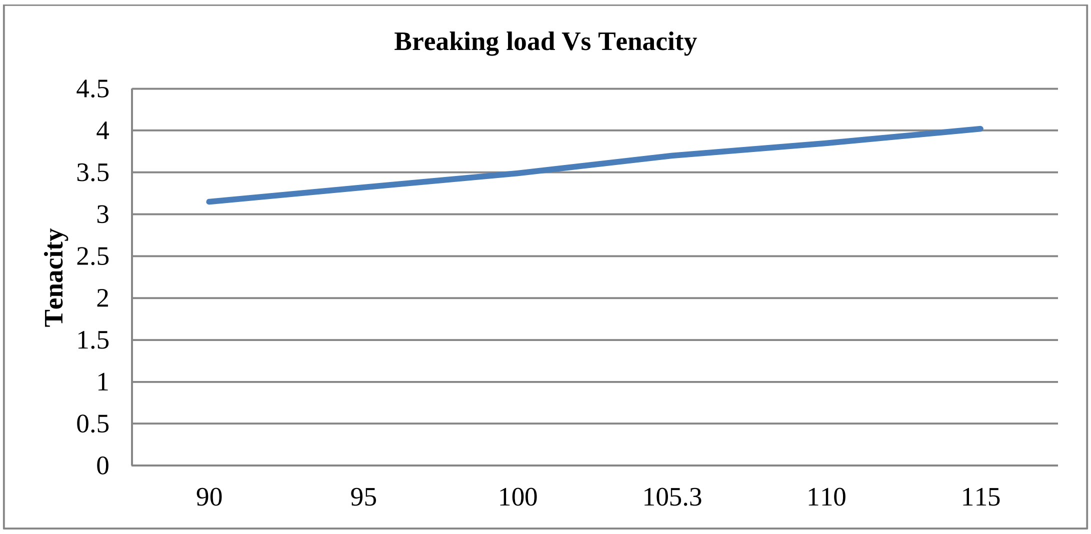

FIGURE IV: A graph showing change in tenacity with respect to changing breaking load of different specimen.

RESULT & DISCUSSION

Silkworm silk and spider silk have been researched to many levels upto many levels and the research is still going on to their absolute optimum application in the field of bullet proofing. For these resources are recyclable and renewable unlike other man made materials used for the same purpose. With this unidirectional approach in mind, an analysis was carried out by me and my professor to suggest potential use of silk in bullet proofing technology [15-22]. The testing were successfully performed at Central Silk Technology Research Institute, Central Silk Board, Bangalore and the results that were obtained are

- Linear density of M V silk sample was found to 28.6 den at CSTRI, Bangalore on 10/08/2016.
- Average breaking load of M V silk sample was found to be 105.3 gf/den at CSTRI, Bangalore on 10/08/2016.
- Elongation of M V silk sample was found to be 14.1 % at CSTRI, Bangalore on 10/08/2016.

TABLE II: Comparison of properties of silkworm silk fiber with other similar materials which are or can be used for bullet proofing

Material	Linear Density (den)	Tenacity (gf/den)	Coefficient Variation (%)	Diameter (µm)
Silk	28.6	3.7	24.8	12.9
Spider Silk	0.126	10.3	14.8	3.57
Kevlar 29	1500	23	6.1	6.1
Nylon-6 filament	2.12	6.9	3.1	16.2
Polyester filament	1.73	9	2.4	13.3
Merino Wool	6.07	15.8	25.6	25.5

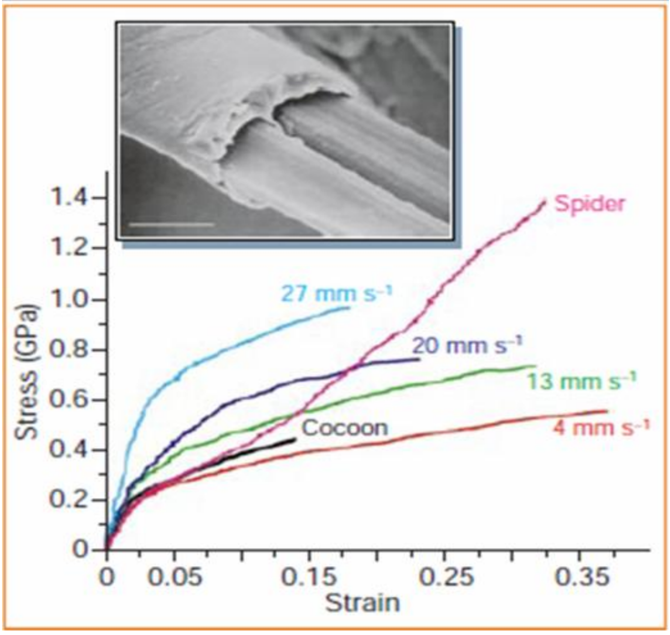

FIGURE V: Graph showing comparison of stress strain curves of cocoon silk and silk worm silk. It also shows the change in curve with change in the reeling speed of cocoon. This figure was obtained from an article named “Surprising strength of silkworm silk” originally published in Nature in September 2002 edition jointly authored by Zhengzhong Shao and Fritz Vollrath

CONCLUSION

From the analysis it was concluded that even though raw silk exhibits fairly low mechanical properties but still has the potential to be used in the field of bullet proofing. It is an experimentally proven fact that ordinarily if 18-30 layers of silk is employeed, the composite will act as a bullet proof wall. It is suggested that if M V silk is compounded with S or E glass to make a composite then that composite can possibly be used as a bullet proofing agent.

Few other complex such as lexan and carbon fibers; and basic materials such as steel and titanium can also be used in the bullet proofing technology along with silk.

FUTURE ASPECTS

- Analysis of other properties of silk apart from mechanical has to be done.
- Composites of silk with other stronger materials such as aramid fibers can also be prepared and studies upon for light weight bullet proofing vests.
- Spider silk is yet another super fiber whose territory is unchartered.

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