The Evolution of one of the World's Most Fire Resistant Fibers – OPF

How advances in technology are bringing life back to the much maligned fiber

By: Steve Bond & Tony Ko | *April 27, 2015*

There is a massive and growing demand for FR fabrics globally. Conservative estimates put the demand in excess of $3B annually. Unfortunately, there are only a handful of *inherently* flame resistant (FR) fibers in the world that can be transformed into yarn, fabric, and, ultimately, FR garments. Each of them have their strengths and weaknesses, but the market is essentially dominated by only 3 (modacrylics, FR Cellulosics, and aramids) – *see table below.* Of the **other** fibers, one stands out as a clear candidate to be considered as one of the prime players – Oxidized Polyacrylonitrile (OPF or OPAN). This paper will examine the reasons for the lack of OPF adoption in the FR apparel market and will discuss advancements in the treatment of OPF that may serve to bring this remarkable material to the forefront of protective fibers. Both garment manufacturers and those who rely on those garments have been seeking an alternative like this for decades.

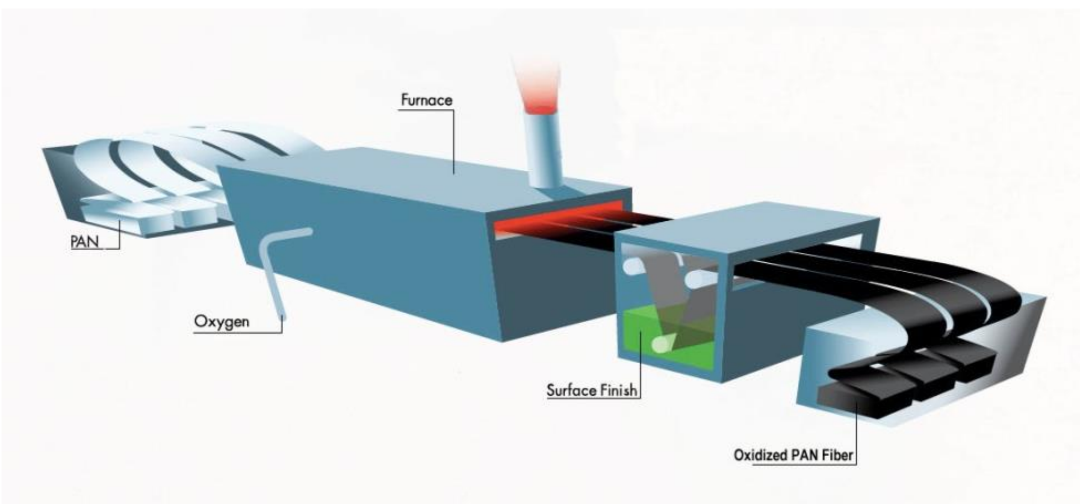
FIBER PROPERTY	modacrylic PROTEX	OPF (OPAN)	novoloid KYNOL	FR Viscose LENZING	melamine BASOFIL	polyamide-imide KERMEL	m-aramid NOMEX	p-aramid TWARON	p-aramid TECHNORA	p-aramid KEVLAR	polyimide P84	polybenz-imidazole PBI
Density, g/cc	1.37	1.37 - 1.40	1.27	1.52	1.40	1.34	1.38	1.44	1.39	1.44	1.41	1.4
Moisture Regain, % @ 20C & 65% RH	0.80	11.0	6.0	13.0	5.0	4.5	4.5	4.5	2.0	4.3	3.0	15.0
Breaking Tenacity, cN/tex (gpd)	29 (3.3)	19 - 23 (2.1 - 2.6)	12 - 16 (1.3 - 1.8)	15 - 24 (1.7 - 2.7)	16 (1.8)	35 (4.0)	35 - 47 (4.0 - 5.3)	200 (23.0)	247 (28.0)	200 (23.0)	38 (4.4)	23.5 (2.7)
Breaking Elong., %	30	22 - 28	10 - 50	15 - 20	12 - 18	23	22 - 32	3.3	4.6	4.0	30	25 - 30
Limiting Oxygen Index, %	**32 - 34**	45 - 55	**30 - 34**	**28**	**32**	**29 - 31**	**28 - 30**	**29**	**25**	**28 - 30**	**38**	**41**
Decomposition Temp., C (F)	220 (428)	>450 (>842)	150 (302)	150 - 200 (302-392)	371 (700)	380 - 400 (716 - 752)	400 (750)	500 (932)	500 (932)	482 (900)	482 (900)	>500 (>932)
Acid Resistance	Excellent	Excellent	Excellent	Poor	Poor	Fair	Fair	Fair	Fair	Fair	Good	Poor
Alkaline Resistance	Excellent	Good	Excellent	Poor	Excellent	Poor	Poor	Poor	Poor	Poor	Good	Good
Organic Solvent Resistance	Excellent	Excellent	Excellent	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Good
Abrasion Resistance	Good	Fair	Poor	Fair	Fair	Good	Good	Good	Good	Good	Good	Good
Ultraviolet Resistance	Excellent	Excellent	Good	Good	Excellent	Good	Poor	Poor	Poor	Poor	Excellent	Fair
Char Shrinkage	Poor	Excellent	Good	Good	Excellent	Poor	Fair	Excellent	Excellent	Excellent	Poor	Excellent
Char Strength	Poor	Good	Fair	Fair	Fair	Poor	Fair	Excellent	Excellent	Excellent	Poor	Good
Relative Price	**	**	**	***	***	****	****	*****	*****	*****	*****	*********

What is OPF?

OPF is unique among FR fibers in that, inherently, it doesn't burn, melt, soften or drip. It has a very high LOI (45-55), and is resistant to bacteria, UV, flash fire, arc flash, molten metal and most chemicals. It is free from halogens and is environmentally and physiologically safe. It only emits a very low toxic gas upon flame and heat exposure. It also maintains its dimensional stability with very limited shrinkage after being exposed to flame and heat.

OPF began with a synthetic fiber invented by DuPont in 1950, called Polyacrylonitrile. The product was branded Orlon. Many other companies now make variations of this fiber most commonly referred to as PAN. PAN is used in a wide variety of industrial applications.

Oxidized PAN (OPF), sometimes referred to as OPAN, is formed when PAN is thermally oxidized in a furnace at temperatures ranging from 200-300° C or even higher. (Illustrated below)

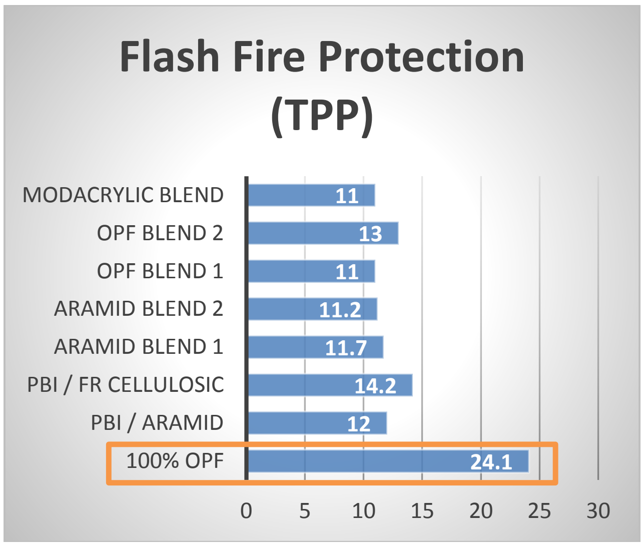


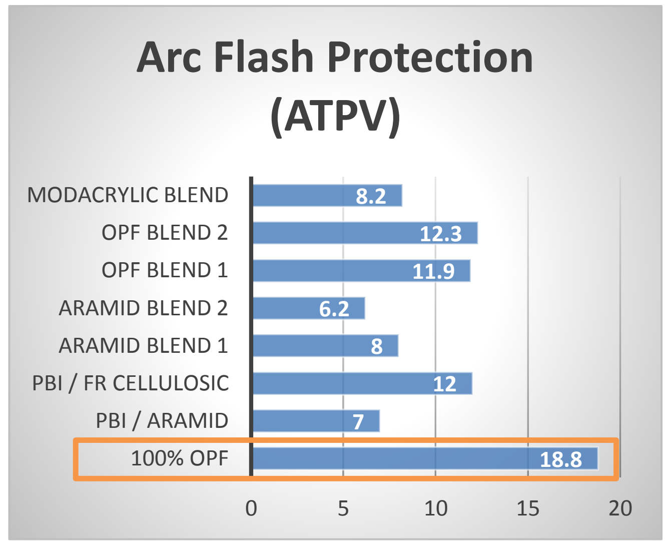
There are two types of OPF filament fiber (also referred to as tow), large tow and small tow. Both are manufactured in continuous filament form without a break for distances exceeding 1,000 meters. Large tow is layered in cartons while small tow is wound on a spool. OPF tow with more than 40,000 (40K) filaments per strand is considered large, while less than 40K is considered small.

The primary use for small tow OPF filament is to make carbon fiber that has many uses including components for aircraft, automobiles, bicycles and golf clubs. Secondary uses include fillers for high-temperature-resistant packing and gaskets. Using their proprietary Direct Yarn Spinning Process (DYSP), Lorica believes it is the first to successfully spin a knittable, comfortable and durable yarn from 100% small tow OPF. DYSP is further explained on page 6 of this paper.

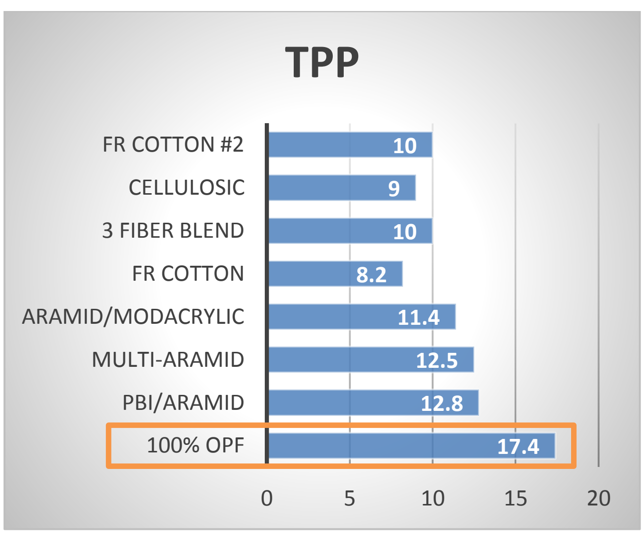
These fiber characteristics obviously carry through to the yarn/fabric/garment as long as they are not treated or blended with other fibers, in which case there may be some dilution in performance. The test results of some comparable FR fabrics shown here clearly indicate the superior performance of 100% OPF (test results are for Lorica 100% OPF).

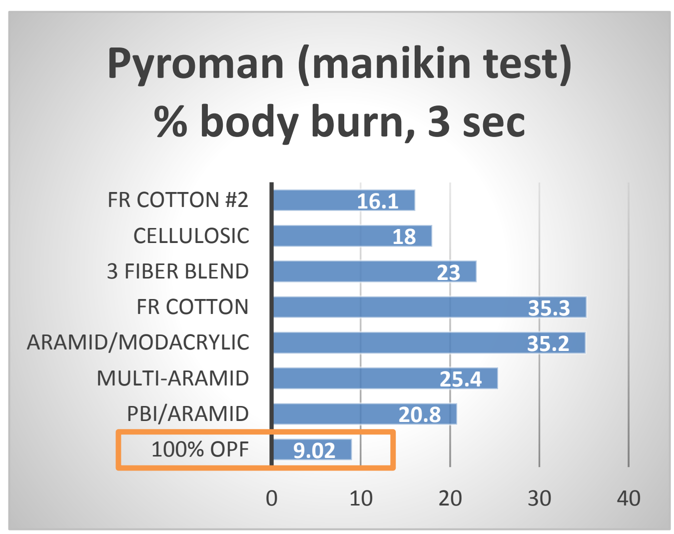
8 to 10 ounce per square yard (osy) Knit Fabric Comparison:





6 to 8 osy Woven Fabric Comparison:





With recent developments in the Personal Protective Equipment (PPE) landscape including more stringent industry standards, heavier enforcement and employer accountability by OSHA, the need for multi-hazard protection, and greater demand for durability and comfort, OPF would seem an obvious fiber to consider. So why not?

Sampling of some FR Industry Standards:

Sponsor	Identification	Comments
ASTM	F 1506	Material for clothing for use by electrical utility workers
ASTM	F 1891	Rainwear for employees exposed to the hazard of flames or electrical arc
CAN/CGSB	155.20	Workwear for protection from hydrocarbon flash fire (Canada)
NFPA	70E	Clothing for employees working on energized electrical circuit parts
NFPA	1971	All fabrics used in protective clothing for structural fire fighting
NFPA	1975	All fabrics used in station and work uniforms for fire fighters
NFPA	1977	Standard on Protective Clothing and Equipment for Wildland Fire Fighting
NFPA	2112, 2113	Selection, care and use of garments for industrial flash fire protection
EN ISO	11611	Protective clothing for use in welding and allied processes (EU)
EN ISO	11612	Protective clothing against heat and flame (EU)
EN ISO	14116	Protective clothing against limited flame spread materials (EU)
EN	469	Protective clothing for fire fighting (EU)

More information can be found at the following websites:

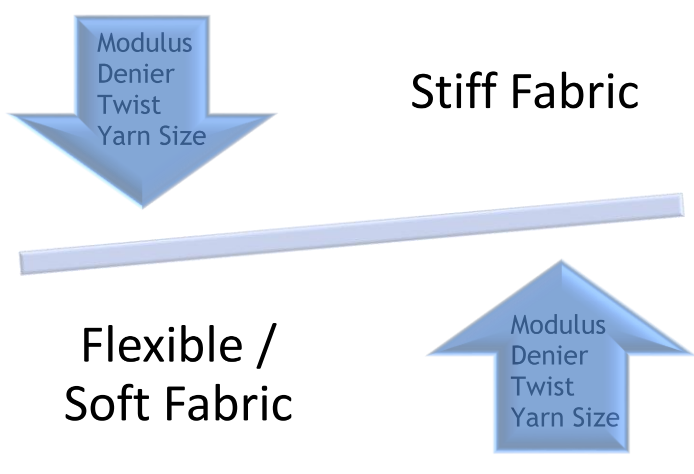
EN ISO	www.iso.org	International Organization for Standardization
NFPA	www.nfpa.org	National Fire Protection Association
ASTM	www.astm.org	ASTM International
CAN/CGSB	www.scc.ca	Standards Council of Canada

Why Hasn't OPF Become a Popular FR Fiber in the Apparel Market?

OPF, by nature, is weak and brittle. The two spinning systems for OPF yarn production are traditional cotton spinning systems and stretch breaking systems using large tow filament (~300k) as the raw material. Both these spinning systems need 8-12 separate steps to produce the finished OPF yarn. Due to the weak and brittle nature of the OPF fiber, each step will do critical harm to the OPF fibers thus causing many short fibers and dust fibers. The resulting yarn is hairy, uneven, weak, brittle, and prone to abrasion, making traditional OPF yarns difficult to weave and especially to knit, so spinners have turned to blending with other fibers, or increasing the fiber width (denier) and stiffness (modulus & twist) to try to solve the problem. Neither has been ideal. The fiber also only comes in black – that cannot be changed.

The drawbacks of blending: If a high percentage of other fibers are added into the OPF blended yarn, then the inherently beneficial properties of the OPF yarn will of course be greatly diluted. If a low percentage of other fibers are added into the blended yarn, then it won't improve the strength of the blended OPF yarn to a meaningful level. Some success has been found in blending OPF with low percentages (~15%) of aramid fibers like Kevlar and Twaron, but when these are spun using traditional spinning systems, the OPF fiber is seriously damaged during the multiple mechanical operations leading to many short fibers and dust in the blended yarn. These will gradually drop out during tender friction and normal washing leading to discoloration, pilling and low durability.

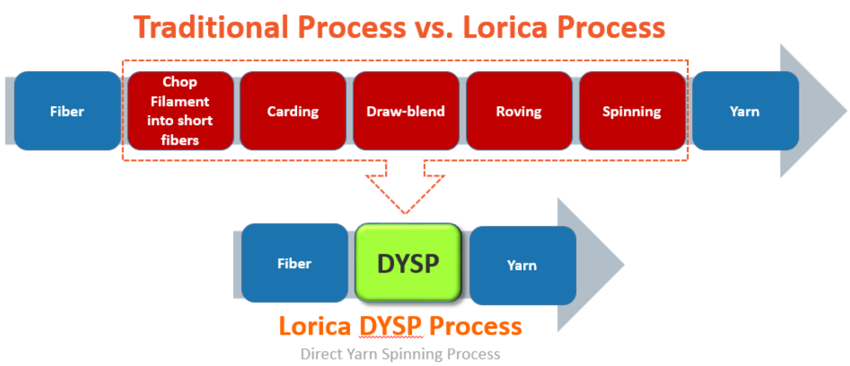
The drawbacks of increasing fiber width and stiffness: In order to spin OPF using traditional methods, manufacturers have increased the denier of the OPF to ~2.0 dpf yielding yarns ranging from 6cc to 20cc. This results in thicker and less flexible fabrics as does increasing the modulus and twist. Neither of these options resolve the issues of inconsistency, weakness and hairiness due to mechanical processing.



These drawbacks point to the need for an innovative spinning system that is mechanically gentler on the OPF fiber to minimize yarn damage while also handling deniers below 1.5 dpf and modulus less than 50 g/d. Only then can the full benefits of OPF be realized in protective apparel.

It is clear that OPF has inherent properties that are critical for innovation in garment/fabric construction and for improved protection for those who need it. Blending OPF with other fibers for strength dilutes the performance of the OPF to an extent that it loses its unique advantages, while current spinning techniques cannot produce a consistent, apparel-worthy 100% OPF yarn. Innovative spinning technologies now show hope of making this possible, such as Lorica's patented DYSP technology. This technology was developed to spin unique fibers into apparel-worthy yarns. The first yarn Lorica has brought to market is a Lorica 100% OPF.

Traditional large tow fibers are spun into yarn using a cumbersome, multi-step process. First, the large tow must be crimped. Second, it has to be cut into shorter staple fibers or stretched and broken into sliver with longer staple fibers. Third, it must pass through multiple processes and machines to form drawn and combed slivers. Fourth, the drawn and combed slivers are taken to a roving frame to form roving that can finally be passed through a conventional spinning frame. This method can require from five to more than 7 steps to form a usable yarn. One example illustrated below.



Lorica's technology applies innovative modifications to a standard spinning frame that eliminate all of the steps and machinery that typically precede it. Lorica starts with high-quality, small tow OPF that conforms to a very precise list of specifications that the Company does not publish. This tow is then fed directly into a spinning frame, stretch broken, and spun into yarn. This is made possible by adjusting certain components of the frame to specific settings that the Company does not disclose. The combination of the OPF specifications and spinning frame configuration is necessary to replicate Lorica's OPF-based products. Furthermore, these settings and specifications are bracketed by ranges in Lorica's intellectual property that the Company believes make DYSP replication infeasible without infringement.

DYSP creates significant savings by eliminating unnecessary steps and their associated variable and capital costs. DYSP also eliminates process errors resulting in more consistent quality and a higher yield on raw materials. Furthermore, the resultant yarn is finer and stronger than what can be achieved in a standard spinning process. The OPF yarn produced can be knitted or woven into a fabric that will not burn, is electrically and thermally poorly conductive, and is virtually impervious to molten metal.

Although the performance of a 100% OPF yarn is clearly superior to any other fiber on the market, the fiber has been somewhat forgotten by the industry as a whole. For the benefit of innovation in the quality and protection we offer our industrial employees, our troops, and our 1st responders, it is time we take a second look at OPF in its purest form. 100% OPF.

About Lorica

Lorica is a technology company developing and manufacturing innovative materials and manufacturing methods primarily in technical textiles and yarns. Our flagship product is Lorica 100% OPF yarns and fabrics – created to address the critical and growing market for light-weight, comfortable, inherently fire-resistant and non-conductive fabrics. Applications include protective apparel in oil and gas, first responder and military markets as well as industrial applications in aerospace, automotive and electronics. www.loricausa.com

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