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Low inertia carbon fiber rollers:

a big step in the performance of coating, laminating and printing machines

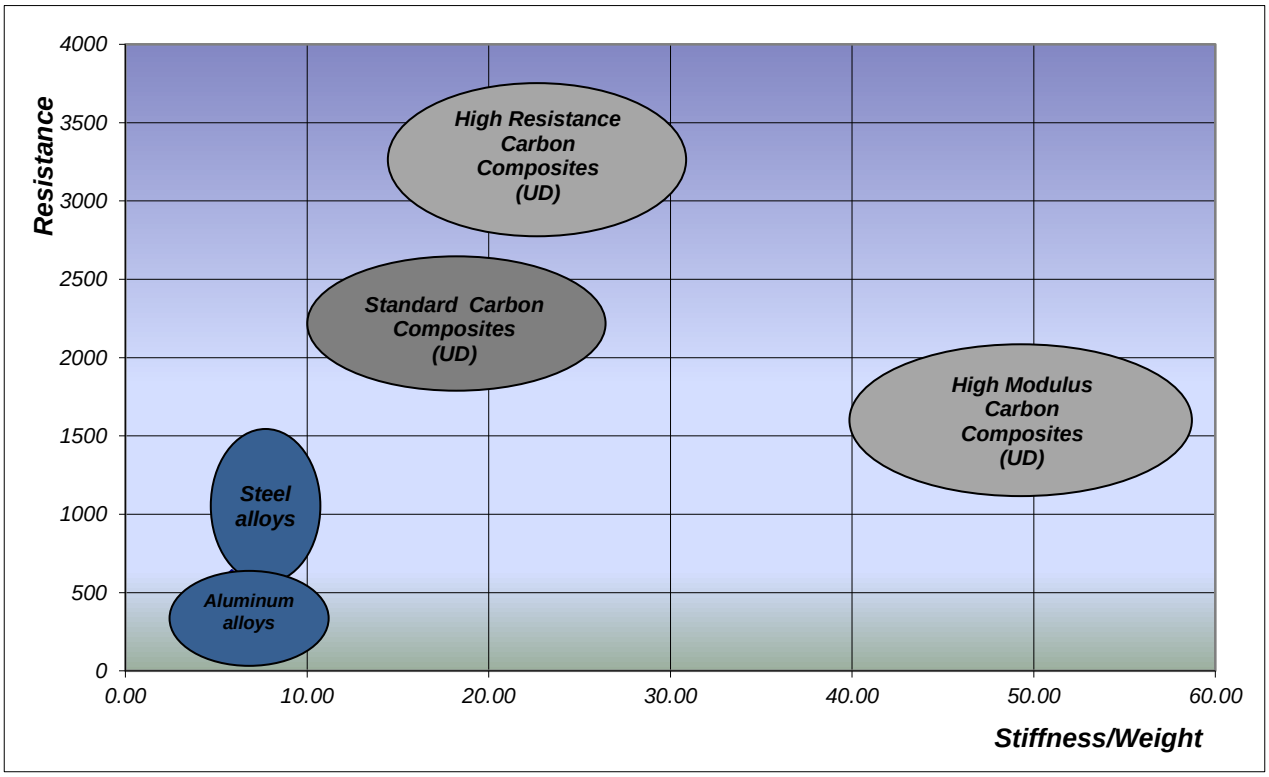
1 – Why carbon fibre rollers

Carbon fibre composite rollers are used since many years in many converting applications in the fields of tissue, non-woven, paper and plastic film.

In those fields it's easy to understand the reasons of this use: due to the increase of the line speed and the width of the web simply there is no way to use other types of material to build the rollers, they could not have sufficient mechanical characteristics to guarantee the performance of the line in terms of speed, quality of the web, energy consumption, and so on.

This is due to the unique characteristics of the carbon fiber composite which can have very high stiffness (up to twice that of steel) and very low density (5 times lower than steel).

The following graph gives an idea of the huge difference existing between metal alloys and carbon composites with epoxy matrix.



A high performance carbon fiber composite is usually composed by an epoxy matrix reinforced with many different types of carbon fibers depending from the performance requests of the component.

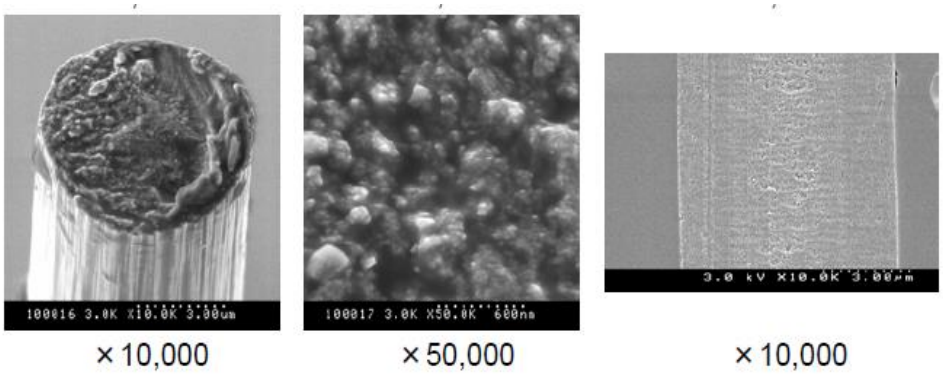
Just to see how the characteristics of the carbon fibers can vary here there are some micro images and features of the 2 main existing categories of those fibers:

PAN fibers

High resistance and toughness

Rt up to 7000 MPa

E 230-300 GPa



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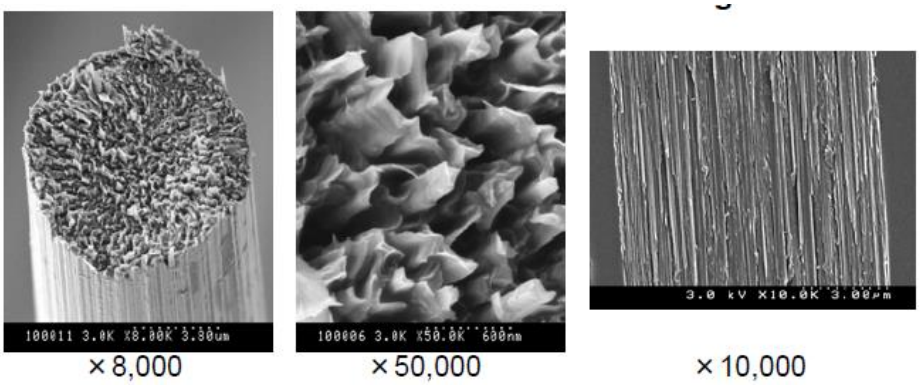
PITCH fibers

Very high modulus but fragile

Rt up to 3400 MPa

E up to 930 GPa



× 8,000 × 50,000 × 10,000

These are, of course, only the fiber characteristics which have to be reduced up to, roughly, half of those values in the UD composite due to the matrix content. The values have to be furthermore reduced in the composite component due to the different direction in which the laminates have to be placed.

At least 90% of the use all over the world of carbon fibers is related to PAN fibers.

Nevertheless, in roller industry PITCH fibers are very important since in the most cases the problems are related with the stiffness and lightness more than with resistance so, very long and fast rotating rollers, have a high content of PITCH fibers to increase the longitudinal elastic modulus of the whole tube up to values of nearly 300 GPa (1.5 times the steel).

In short, the advantages of the carbon rollers can be summarized as follows:

- ***Higher speed and lower weight :*** Carbon rollers for converting machines usually have twice the critical speed of the corresponding steel rollers, with a weight that is 10-15 times lower.
- ***Wider formats:*** Due to the stiffness and lightness of carbon the film working formats can become wider and increase production.

- ***Lower starting time:*** Thanks to the lower inertia the plant starting time can be overwhelmingly lower with a better efficiency in production.

- ***Many rollers don't need to be powered:*** Often metallic rollers, due to the weight and lightness of the film they carry, need to be powered and controlled by complex electronic systems in order to avoid stretch or damages. The lightness of carbon is such that even a light film traction can move the roller, saving all cost derived by motors, electronic drivers, control systems and energy necessary to power it.

- ***Better precision in load cells:*** Dancing rollers or every roller installed on load cells, if made of carbon fibre, form a lower tare weight. This means that the actual film tension can be read with greater precision and quickness from smaller load cells.

- ***Possibility of diameter reduction:*** With carbon fibre the diameters of the rollers can be reduced with many advantages in the geometrical design of the machine which can be more compact and economical.

- ***Reduction of surface contact:*** Another advantage of smaller diameters comes by reducing, at same angles, the contact area between film and roller. This means there are fewer possibilities to damage the film and less interferences during its course.

- ***Reduction of structural loads on the machine:*** The use of carbon rollers in converting machines does not only increase working speed and the width of material but reduces the loads and vibrations on the structure that can become lighter and economical with less electric power involved.

2 – Carbon fiber rollers in coating and laminating machines

What said before has led to consider a normal and forced choice the use of carbon fiber rollers in plants with web widths of 2.7 m or more and speeds of at least 6-700 m/min while for lower sizes aluminum rollers are still the standard choice due to their lower cost.

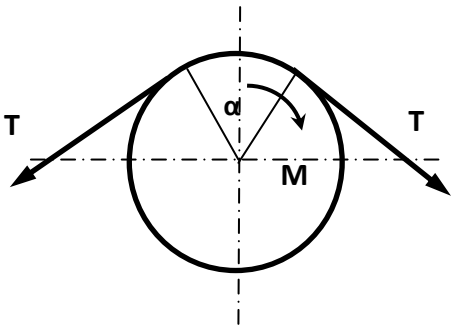
Our experience show now that even with web widths lower than 2 m the advantage of using carbon rolls is absolutely effective and can solve many problems particularly with thin films and metallized films which can be easily damaged and scratched by high tension or friction on the roller.

In every roll to roll process anyone faces two different problems related to the web handling and the possible associated damages:

- ***Start and stop of the machine*:**

  in this case there are 3 parameters having a big influence:

  - *The moment of inertia of the roller*
  - *The wrapping angle of the web*
  - *The surface friction coefficient of the roller*



The torque **M** can be expressed as follows:

$$M = 2\mu r\, T \sin(\alpha/2)$$

$$M = J\dot{\omega}$$

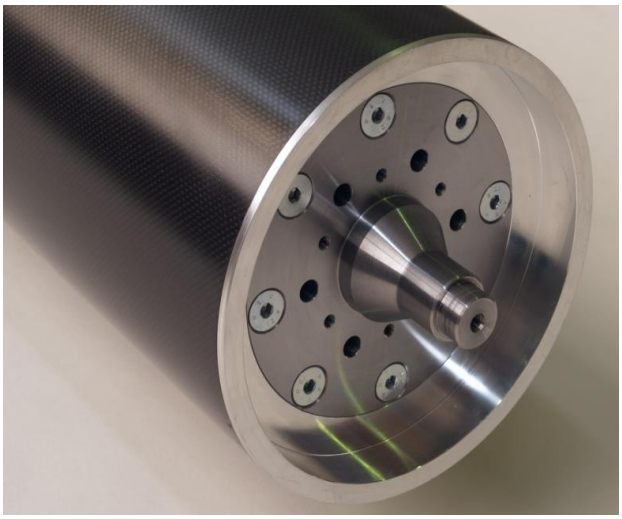
Where: **T** web tension **J** roller moment of inertia
r roller radius **α** wrapping angle
μ surface friction coefficient

It can be seen that the most important parameter is undoubtedly the *moment of inertia* of the roller. The lighter the roller the lower the torque M needed and easier to put the roller in rotation and to accelerate.

Of course also the *wrapping angle* and the *surface friction coefficient* have an important role but they can *increase* the torque M while we need to maintain it as low as possible (but without slipping) to avoid damages on the web.

Moreover the wrapping angle can be hardly increased without changing the machine geometry and this, usually, cannot be made. Relatively high *friction coefficient* can help but it cannot be increased so much without disadvantages, since, with heavy rollers, it can create a too high traction on the web.

The carbon roller, in comparison to a classical aluminum roller which it can replace, has *a moment of inertia 3 times lower in average*. Carbon fiber rollers are therefore much easier to accelerate even with thin and delicate webs that, with metal rollers, require a powered acceleration and deceleration to avoid web damages.

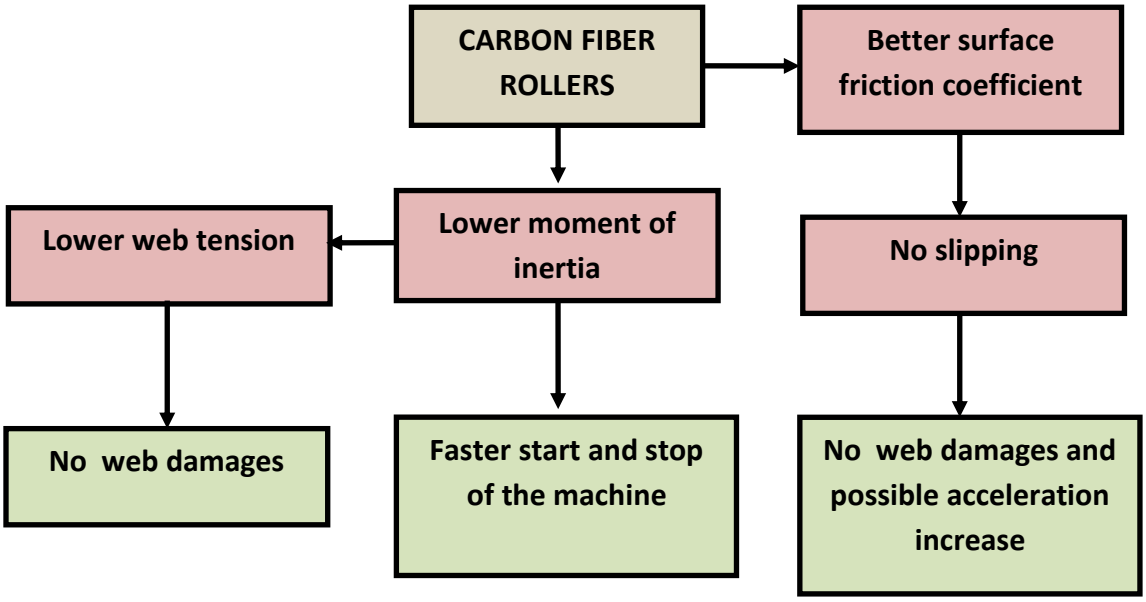


The advantage increases as smaller is the wrapping angle of the web along the roller.

Furthermore, certain carbon rollers (as this represented on the left) made with prepreg technology have a surface made in carbon fabric which present a peculiar surface friction coefficient slightly higher than that of aluminum but not so high to create problems on the web.

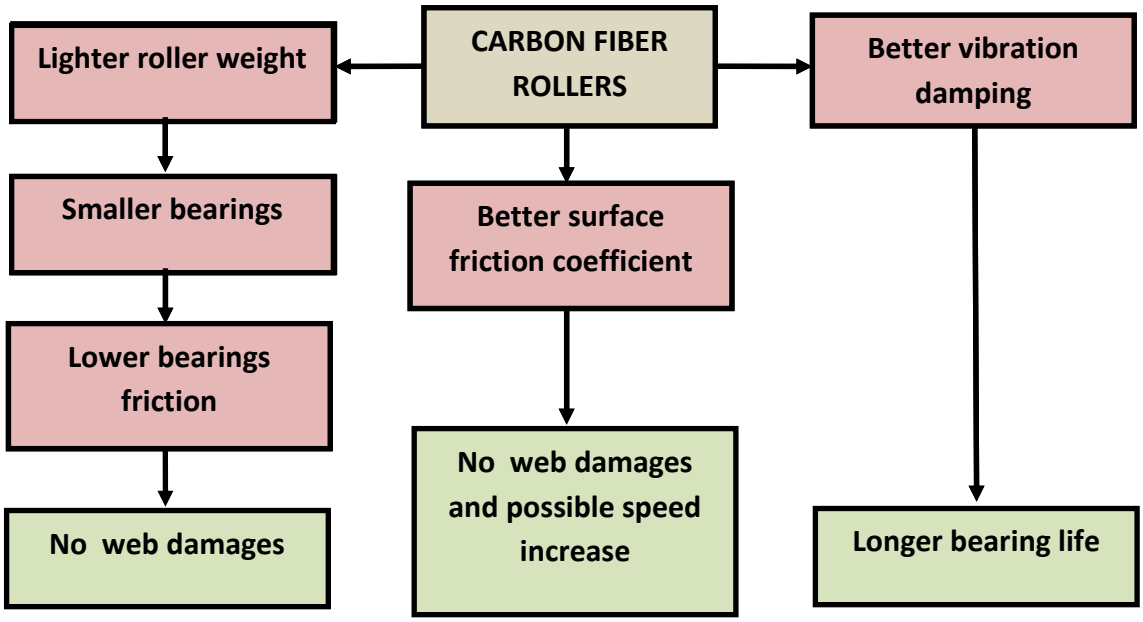
That friction coefficient is very suitable for delicate web and light rollers while the surface has also a very good wear resistance.

The **consequences of the use of carbon rollers in start and stop of the machine** can be summarized as follows:



- ***Machine operation at working speed:***

the most important parameter in this phase is the *bearing friction*. The rollers need to be maintained in rotation by the web and therefore lower the bearing friction smaller the influence on the web. If, furthermore, smaller bearing can be used the friction can be further reduced.
Due to the usually small web tension with delicate films, the weight of the roller is the main parameter for the bearing size and thus affects the friction. Moreover in many cases, due to their better vibration damping, carbon fiber rollers allow a higher durability of the bearing permitting a longer maintenance intervals in the machine. So the **consequences of the use of carbon rollers in the normal operation** are:

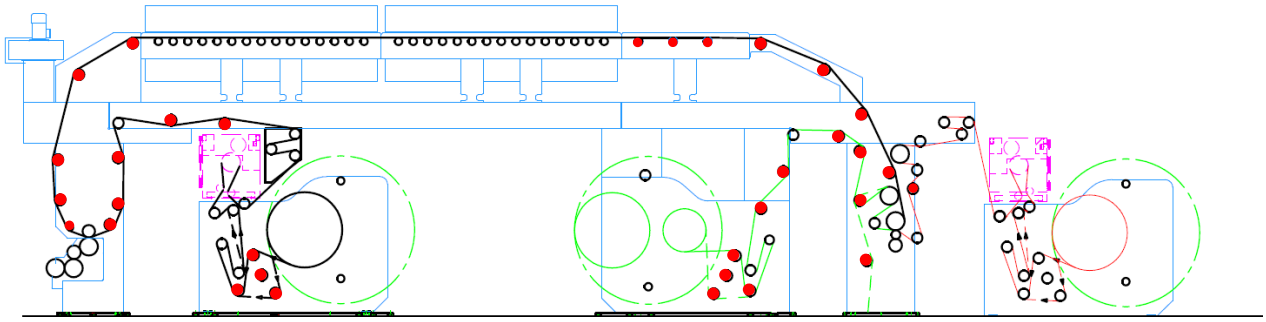


3 – Operating applications

Herebelow it can be seen a scheme of a Nordmeccanica Duplex Combi machine.

This machine has a big number of low wrapping angle roller positions in which carbon fiber rollers could be very effective for the reasons explained before.

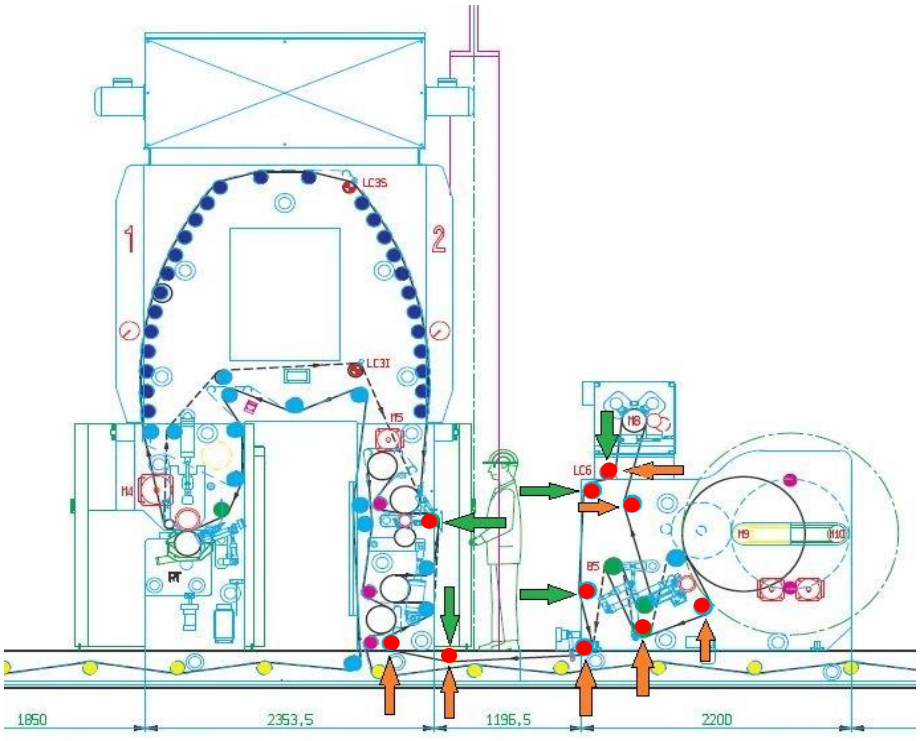
The most useful positions have been marked in red while many other positions could be covered with carbon fibre rollers.



Nordmeccanica Duplex Combi machine: in red the rollers which can be advantageously replaced with carbon rollers.

There are many final users which have replaced (with the agreement of the machine manufacturer) the standard aluminum rollers with carbon fiber rollers with a dramatic improvement of the film quality.

In another Nordmeccanica triplex laminator the following rollers have been changed with a very good quality improvement of the web.
The rollers are indicated in red in the sketch on the left.



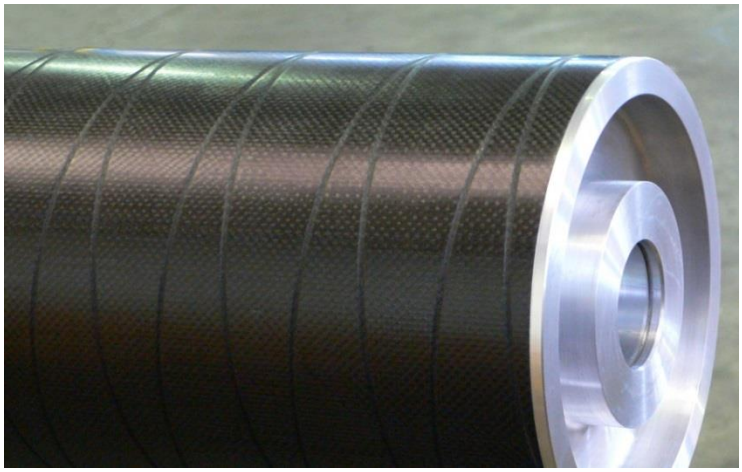
This replacement has consistently improved the rotation of the rollers with stretchable materials like PE or CPP for which very low tension values are used during the process.

All the scratches disappeared after the replacement of the rollers.
We recommend, in case of replacement, to evaluate the possibility to reduce the bearing size (as explained before) replacing also the inner shaft with a smaller one.

Other very important applications have been made completely replacing the idle rollers and guide rollers of a ***rotogravure*** printing press in which metallized OPP and PET were heavily damaged and scratched by the slipping of the roller which cannot be put or kept in rotation by the web.

Same operation has led to a very effective improvement in the web quality in a ***flexographic*** printing press used for delicate webs.

Coating, laminating and printing machines can have further problems as the avoiding of the web lifting for the air cushion between rollers and web, wear resistance of the roller surface and the avoiding of sticking to the roller for the already coated web. Carbon fibre rollers can have all the requirements to solve those problems in the same way or better than the aluminum rollers.



Air elimination:

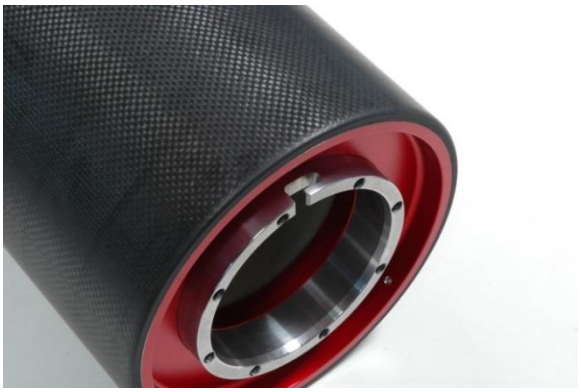
High speed machines, depending on the web tension and can have the problem of air elimination between roller and web.

In fact, fast rollers can drag in rotation air which lifts the web, preventing the contact with the roller, reducing the rotation and creating web damages.

As happens in aluminum rollers, carbon fiber rollers too, can be provided with grooves to eliminate the air and, having the possibility to reduce the roller diameter, can be more efficient also in this aspect in front of an aluminum roller.

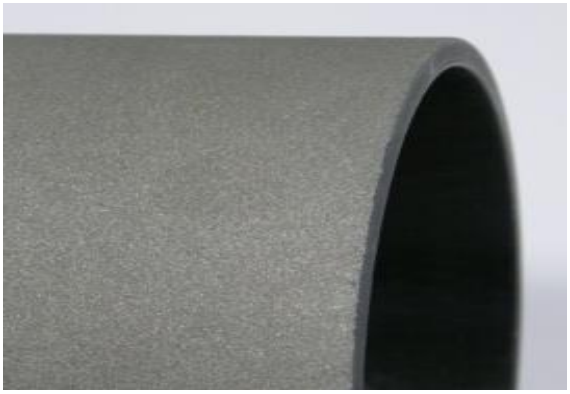
Wear resistance:

If a carbon fiber roller is made with a prepreg wrapping technology can be provided with a carbon fabric surface. In this case its wear resistance is by far better than the aluminum surface and even better than anodized aluminum.

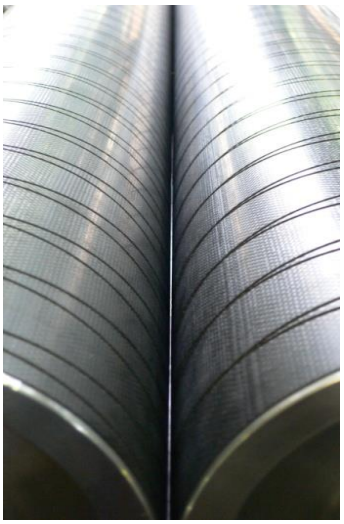


Surface coatings:

Carbon rollers can be provided with many different types of coatings, from rubber and elastomeric coating up to hard thermal spray coverings.
In coating and laminating machines it is, for some rollers, very important to have the right covering in order to avoid sticking with the rollers. A high roughness thermal spray with a silicone sealing is confirmed as the best and durable ***antisticking*** solution and can be applied on high quality carbon rollers.



To give an evidence of the better characteristics of carbon fiber rollers compared to the aluminum rollers a comparison table can be seen herebelow for a typical size roller.



	Aluminum roller		Carbon roller
Diameter	**150**	mm	**150**
Face length	**2500**	mm	**2500**
Average thickness	**5**	mm	**3**
Roller weight (incl. ends)	**17.17**	kg	**6.89**
Roller Moment of Inertia	**879**	$kg*cm^2$	**345**
Longit. Young modulus	**70**	GPa	**120**
Stiffness Ex*Jx	**41952**	$Gpa*cm^4$	**44926**

It can be noted that with the same size of a relatively small roller, a carbon fiber roller can have a reduction of weight and moment of inertia of about 2.5 times with a higher stiffness.

Moreover, while aluminum rollers have fixed characteristics, carbon fiber rollers can be designed to meet many different needs, so they can have much higher stiffness or can be even lighter than this here indicated. The difference comes much more evident as the size increases.

In conclusion, notwithstanding their higher price, carbon fiber rollers can give to the machines so many advantages that its cost increase can be considered negligible in comparison to the lower material waste, better quality and higher production speed which can be achieved.

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