A review of carbon fibre rollers in the printing, papermaking and allied industries

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Abstract

The use of carbon fibre in industries such as aviation and automotive is already well documented. Carbon fibre combines strength with a low weight making it an ideal material for aircraft and motor racing parts where weight is a premium. Its use in the printing industry for rollers and cylinders is not well documented despite the fact that it is being used, albeit infrequently, and its use is normally not advertised. However, there is an increasing trend for using carbon fibre for components such as print cylinder sleeves for easier handling and idler rollers as they can reach higher rotational speeds than metal rollers for a given diameter. This is particularly important when wide web widths are used such as in papermaking and polymer film manufacturing. Their use is also likely to increase in the industry due to the manufacturing tolerances of emerging industries such as flexible electronics and solar.
This report aims to review the use of carbon fibre rollers in the printing industry as well as some of the other industries that are allied to it

Stichwörter: carbon fibre, idler roller, printing cylinder
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Introduction

The printing industry is one of the world's largest industries and encompasses not only the products typically associated with it such as publication and packaging but it is also used in the manufacturing of products such as designer handbags and laminate flooring, automotive parts, household appliances, and textiles. The global print market reached 785 billion USD in 2017 [1].

In many of the processes used for printing and coating, as well as the manufacturing of substrates such as paper and plastic films, a long continuous belt of the substrate, known as a web is used. These processes rely on a series of rollers to guide and transport the substrate through the machines and control its tension as well as transfer inks and coatings onto the moving web. Traditionally these rollers were made of steel or aluminium, however, lighter weight composite materials such as carbon fibre are now being used to replace some of these rollers. The aim of this report is to review the current and potential future use of carbon fibre rollers in the printing, paper, and allied industries.

The current use of Carbon Fibre Rollers

The first recorded use of carbon fibre was by Thomas Edison in 1880 during his development of the light bulb [2], where he carbonised a cellulose fibre to use as a filament. Further development in the 1950's led to the first patent for Polyacrylonitrile (PAN) based carbon fibres in 1959, which is the dominant precursor used for most carbon fibre applications today [3]. The first carbon fibres from pitch precursors were first manufactured in 1975; these result in a lower yield than PAN-based fibres but have higher elastic moduli. Carbon fibre rollers contain a high content of pitch fibres due to their higher stiffness [4].

Carbon fibre products are already being used in various capacities in the printing and coating industries, although the uptake is very much in its infancy. Currently one of the primary uses of carbon fibre is for components that need to be regularly removed from the printing press such as ink chambers and sleeves used for both anilox rollers and printing cylinders in flexographic printing. These both require a combination of low weight for easy handling with precise mounting on a mandrel, and high stiffness to ensure consistent ink transfer. Early sleeves were manufactured from glass fibre, but more manufacturers are now using carbon fibre because it offers a high stiffness for more accurate and consistent ink transfer making it an ideal choice for these components, particularly for wider web widths. One of the first systems for carbon fibre plate cylinders sleeves was developed by Rossini [5], other manufacturers including *Fischer and Krecke* [6] (now part of *König and Bauer*) have followed suit. Most manufacturers of wide web flexographic printing machines use sleeve technologies for the printing plates; for example, König *and Bauer* are offering carbon fibre mandrels as an option on their *Evo* and *Neo* flexographic printing machines [7]. This is shown in Figure 1.

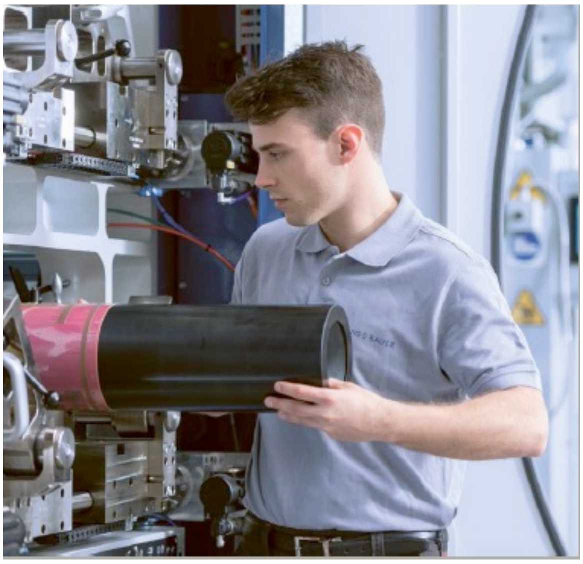

Figure 1 – Flexographic plate sleeve system from König und Bauer [7]

Rossini have subsequently developed a carbon fibre bridge sleeve for adapting different sized printing sleeves so that different repeat lengths can be achieved [8].

In rotogravure printing, the printing cylinders have traditionally consisted of a steel cylinder that is plated with copper and chrome. Cylinder manufacturers have experimented with several combinations of materials [9] [10] in order to reduce the weight of these engraved cylinders to improve handling without compromising the print quality. One solution is available from *Janoschka* [11], which is based on a patent from *Sachsische Walzengravur* [12] uses the Coupling Effect of carbon fibre to secure the sleeve onto the mandrel, minimising distortion and alignment issues.

Carbon fibre rollers are used in some offset printing machines in the roller trains for inking and damping systems. A patent for carbon fibre inking rollers was filed by *Man Roland* in 1996 [13]. Other offset press manufacturers such as *König and Bauer* have subsequently patented carbon fibre inking rollers [14] [15]. *König and Bauer* incorporated carbon-fibre inking rollers for their C-series web offset machines [16] stating that these reduced vibration resulting in smoother running rollers and better process stability. These rollers are often coated with elastomeric materials to provide the ink transfer properties required [17] [18].

The area that sees the largest growth potential for carbon fibre rollers is for web handling. These include idler rollers and tension rollers. These are used extensively in printing machines and paper making machines as well as machines for metallizing, laminating and other converting operations. Printing machines for packaging, typically vary in web width from 0.3 m to 1.6 m and operate at speeds between 200 to 600 m/min. While for publication applications, printing presses can have web widths of over 4 m and operate at speeds of over 1000 m/min. It is the wider web widths that see the largest potential benefits of carbon fibre rollers.

The main printing processes using idler rollers are web offset, flexographic and rotogravure, these combine high printing speeds with wide webs for applications such as publication, packaging, decoration. The publication industry in Europe is dominated by web-offset and rotogravure and includes printing press manufacturers such as *Man Roland*, *König und Bauer,* and *Cerutti*. The flexible packaging industry is almost exclusively split between rotogravure and flexography with press manufacturers such as *Bobst*, *Uteco*, *König and Bauer*, *Cerutti, Comexi* and *Windmüller and Hölscher*. Decoration printing is dominated by rotogravure and includes applications such as wood effect for furniture and laminate flooring and also decorative patterns for luxury goods such as designer handbags. Traditionally the web rollers are manufactured from either steel or aluminium and are often coated depending on the requirements. In 2003, *König und Bauer* announced that their TR12B Rotogravure press would utilise larger diameter carbon fibre idler rollers to provide a smoother acceleration and more uniform web tension [19].

Another application for carbon fibre rollers is in papermaking machines, these are typically between 1.5 m and 10 m wide and operate at speeds of over 1000 m/min. *Voith*, a leading manufacturer of machines for papermaking are using carbon fibre for their breast rollers to improve the distribution of fibers, reducing flocculations and therefore increasing the quality and strength of the paper. They have also replaced some of the rollers in the drying section from steel to carbon fibre to increase the production speed of the machines to over 1600 m/min [20].

Packaging uses an extensive amount of polymer films such as polyethylene and polypropylene. This also requires the use of rollers to transport a web of material. Here the polymer is usually melted and extruded through a circular die. Air is blown through the die forming a ‘bubble’ of the polymer which is stretched into a thin layer. This ‘bubble’ is then collapsed using rollers and then wound onto a reel. On modern machines, carbon fibre is used for the bubble collapsing rollers due to their low thermal conductivity, approximately 1000 times less than aluminium, and low inertia to minimise thickness variations and wrinkles [21]. *Kampf* a manufacturer of slitting and winding machines used for polymer film production, use carbon fibre rollers for web handling on their machines that can be up to 10 m wide and operate at 1500 m/min.

The metal web transport rollers in other machines such as laminators and vacuum coating metallizers are also being replaced with carbon fibre rollers [4]. These machines also have production speeds of 1000 m/min with web widths up to 4 m.

The benefits of Carbon Fibre Rollers

For idler rollers, steel and aluminium are the materials that are traditionally used. These can be precisely manufactured to high tolerances and provide the necessary stiffness needed by the rollers, especially over a wide web width. Steel rollers are traditionally used for machines that use paper-based substrates. But due to its high density, steel rollers have high inertia, requiring more energy to drive the press and can result in the rollers rubbing against the substrate as the press speed is increased or reduced. This can result in damage to the print and dust, which can lead to print defects such as hickeys and could also potentially pose a health risk to operators. When compared with steel rollers, aluminium rollers have a lower density and hence a lower inertia and are therefore often used for more delicate substrates such as polymer films, aluminium coated substrates and light paper stocks, which are more prone to scratching and stretching.

At higher press speeds and larger web widths, the critical speed of rollers is an important parameter. This is the speed at which the natural frequency of the roller is induced and is related to the stiffness, mass and the length of the roller. Rollers must always be used below their critical speed or a vibration will be introduced into the web leading to problems with tension and registration among other issues. Metal rollers due to their mass, have relatively low critical speeds, therefore as the web width is increased, their critical speed is reduced therefore limiting the maximum line speed of the machine. This problem can be overcome by either utilising larger diameter rollers or materials with a lower mass while retaining the stiffness requirements.

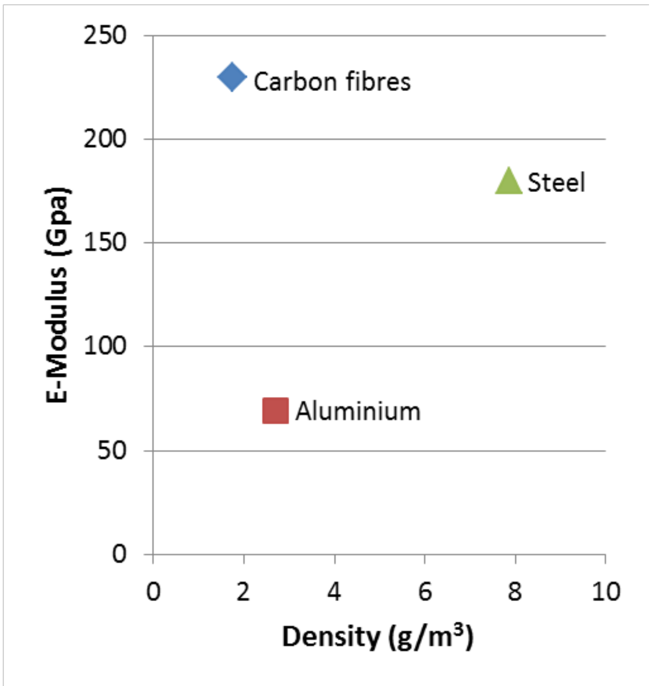

Figure 2 - Elastic modulus versus density [23]

A comparison between the Elastic moduli of carbon fibres, aluminium and steel is shown in Figure 2. Carbon fibre rollers have a significantly higher stiffness to mass ratio than metal rollers [22], which significantly increases their critical speed and therefore higher production speeds can be achieved with less vibration. This also allows for smaller roller diameters to be used.

Due to their lower rotational inertia compared to steel and aluminium rollers, carbon fibre rollers respond quicker to changes in line speed, this reduces the rubbing between the roller and the substrate and therefore reducing damage to substrates and coatings, roller wear and also reduces dust, therefore leading to fewer print defects. The faster response should also bring other benefits such as improved tension control and less start-up waste. The lower mass of the rollers should also lead to less bearing wear and therefore increased bearing life, which is an important consideration when comparing the cost of rollers, as it should result in less downtime. Also smaller bearings can be used which have a lower rolling resistance and when combined with the lower mass of the rollers would result in a reduction in the overall energy requirements of the machine. The rollers can be coated [22] to improve their resilience to wear and chemical attack as well as to alter their thermal and electrical conductivities.

A low mass also means that rollers and cylinders can be more easily and safely handled. For components such as printing cylinders in flexography and rotogravure which need to be changed for each print job, this is a major consideration as lightweight cylinders can be more easily installed and removed from the machines. This can not only reduce the risk of injuries to personnel due to manual handling but also reduce the risk of damage to cylinders and machines stemming from handling difficulties. The other advantage of low mass cylinders is from a storage perspective, rotogravure cylinders are usually stored for use in repeat jobs. Traditional rotogravure cylinders require heavy duty racking and require more storage space than lighter weight cylinders.

Carbon fibre products are constructed from a composite material consisting of carbon fibres in a polymer matrix. Because the fibres are orientated in one direction and due to the difference in properties between the fibres and the matrix material, its mechanical properties are anisotropic. By combining several layers of the composite material where fibres are orientated in different directions, a wide range of mechanical properties such as tensile strengths, torsional and bending resistances can be achieved.

This "coupling effect" can be used to provide certain properties in specific directions and therefore this can be exploited in ways that are not possible with more traditional materials. One such example is the *proRoto* sleeve system from *Janoschka*, Figure 3.

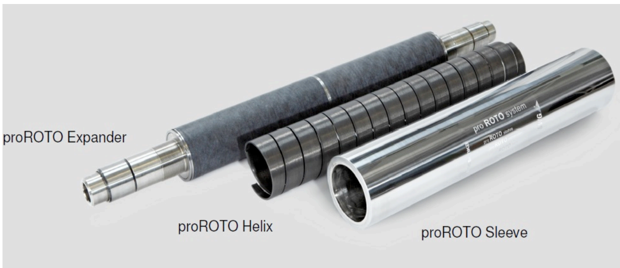

Figure 3 – proROTO Rotogravure sleeve system [24]

This consists of a carbon fibre mandrel that has been designed based around the coupling effect. The addition of a mechanical force, results in a uniform increase in the diameter of the carbon fibre expander in order to grip a printing sleeve. Conversely, removal of this force reduces the diameter of the mandrel allowing the printing sleeve to be removed and replaced. This has some potential advantages over the more commonly used air mandrel systems, where the grip can vary along the length of the mandrel.

Vibration is an area that machine manufacturers strive to reduce. The vibration damping properties for carbon fibre is better than for metals [25], which could also be particularly beneficial for printing cylinders and inking rollers, where any vibrations manifest themselves in variations in ink transfer and therefore have an adverse effect on the image quality.

Current trends

The recent trend in the printing industry is shorter production runs [26] [27], Figure 4. As production lengths decrease the setup time and start-up waste are significant cost parameters and therefore need to be minimised. With this printers are relying on some of the lean manufacturing and Six-Sigma tools to reduce downtime and increase their productivity. One area of this is improving job changeover times with Single Minute Exchange of Dies (SMED) techniques. The use of low weight sleeves in Flexography and Rotogravure help to reduce the changeover times alongside the increased usage of machine automatization. Lower inertia idler rollers in web-based machines could also result in production quality being reached quicker and therefore reducing start-up waste as well as minimising damage to the print during the production run. Minimising how often idler rollers or bearings need to be changed is also a consideration in the reduction of downtime.

The overall maximum printing speed of machines has largely remained static over the last decade; however, web widths have increased to help improve the overall efficiency of the printing machines. Increasing the length of rollers pushes the rollers closer to their critical speed, which means that it is likely that some of the web-based machines for flexography, rotogravure and offset printing utilising steel or aluminium idler rollers are operating close to their critical speed. For manufacturers to increase speeds or web widths in order to further increase efficiencies, carbon fibre rollers or larger diameter rollers will need to be considered.

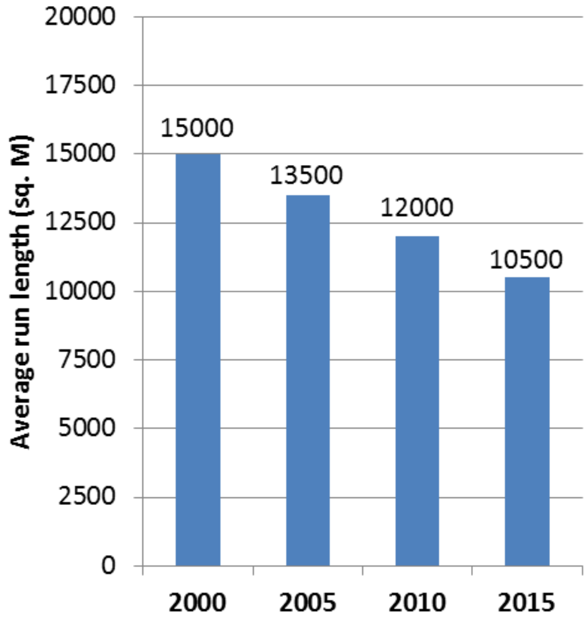

Figure 4 – Decline in average run length 2000 to 2015 [27]

The shift to shorter production runs has led to a rapid growth in digital printing [28] as these machines have little to no setup waste or make ready time. Currently, these digital printing machines, such as *Hewlett Packard's HP T400*, have maximum speeds of around 300 m/min and web widths up to 1 m and therefore the critical speeds of metal idler rollers are far from being reached. However, this is a rapidly developing market and web widths and speeds are likely to increase. But while digital printing machines do not require the higher critical speeds of carbon fibre rollers they can still benefit from the other advantages of lightweight rollers such as the lower energy requirements and improved control.

The overall demand for printed products is expected to increase between 2017 and 2020, but the current trend in the publication market in Europe and North America is expected to continue to contract. The market for publication and commercial printing is continuing to grow slowly in some of the Asia-Pacific countries such as India [29], which could partly be due to books and other publications being exported to Europe [30]. This overall market contraction is likely to limit the sales of new printing presses for commercial and publication printing, which tend to be high speed and wide webs and therefore benefit the most from carbon fibre idler and inking rollers. The global demand for packaging is, however, increasing [31]. The largest growth is also expected in the Asia-Pacific countries with average growth of up to 6.9% [29] is likely to lead to more printing machines for packaging being built and also more demand for polymer films and hence substrate manufacturing equipment. A DRUPA report from 2018 [32] showed that printing companies were more likely to invest in new sheet-fed offset machines for the commercial, publishing and packaging markets and flexographic presses for packaging printing.

Currently, the largest market increase for carbon fibre rollers is replacement rollers in existing machines. Rollers need to be periodically replaced; however, this can result in significant capital expenditure. The price of metals have seen large increases in the 2 year period from July 2016 to July 2018 [33], with steel prices doubling, and aluminium prices increasing by approximately one third. This has narrowed the difference in the cost of replacing existing metal rollers with carbon fibre.

It should be possible to exchange metal idler rollers in most machines for carbon fibre equivalent rollers; however, it is advisable to first consult with the machine manufacturer.

New markets that utilise printing and coating processes are also growing, which include flexible solar panels. While these do not require the high critical speed capabilities that carbon fibre rollers provide, the manufacturing process demands a greater precision than required for graphics printing and therefore greater control over the web handling. Also, the printed devices are sensitive to damage that might come from dragging, therefore carbon fibre rollers could be beneficial due to their lower inertia.

Future trends

As stated previously, if machine manufacturers intend to increase operating speeds, or increase web widths to further improve the economics, this would increase the likelihood of carbon fibre rollers being required unless manufacturers are willing to use larger diameter rollers. The trend of shorter runs and therefore the need to reduce start-up waste will continue as will the need to reduce energy usage and carbon footprints. This will likely lead to more printing machines having carbon fibre rollers fitted as standard.

The cost of carbon fibre rollers is likely to reduce as demand and competition increases and also as manufacturing efficiencies improve. When combined with the increasing price of metals this could make their inclusion more attractive to OEM's even for applications where the critical speeds are not a factor. The user could also see benefits in the longer term due to less downtime for maintenance, particularly when the rollers are coated to increase their life. The greater use of carbon fibre rollers would also lead to further developments and improvements in coatings. However, it is with the increasing number of Chinese and Indian built machines that could see the largest growth in carbon fibre rollers as they try to compete for machinery sales in western markets.

Currently, there is significant research and development of printed and flexible electronics as well as biomaterials. These technologies utilise printing and coating techniques as well as flexible substrates in the manufacture of devices including smart packaging, flexible displays, lighting, wearable technologies, medical sensors, batteries, and photovoltaics. While the manufacturing industry for these is currently relatively small; it is an area that is forecasted to grow at an annual rate of 13.6% to over 26 billion USD [28] over the coming years and demand high levels of control and precision over web and sheet movements [34]. The value of these products is significantly higher than for graphics printing and any damage from scratches could result in a faulty device. These applications would benefit from low inertia rollers [35].

With the growing trend towards Industry 4.0 and therefore greater amounts of automatization, carbon fibre rollers and especially carbon fibre sleeves, have a significant advantage over their metal counterparts, as smart objects such as RFID tags can be more easily incorporated into them. Metals can cause problems for RFID tags as they reflect the energy emitted from an RFID reader and induce interference for RFID antennas, which means that the tags are difficult to read. Carbon fibre on the other hand, does not interfere with the signal and therefore the information from RFID tag can be more easily accessed. An example of where this could be used is part of an inventory system for printing cylinders, allowing the correct cylinders for a job to be automatically identified, removed from storage and inserted into the machine as part of an automated changeover system.

Conclusions

Carbon fibre combines a high stiffness with a low mass, as such, it is being used for printing cylinders and other components that need to be changed regularly, therefore, minimising the risk of injuries due to handling.

A high stiffness to density ratio also significantly increases the critical speed of rollers. This has many benefits particularly for web transport rollers due to their potential to achieve higher rotational speeds and also wider web widths.

The low inertia of carbon fibre rollers can result in less rubbing of the substrate, therefore minimising damage to the print or to coating and also reducing print defects resulting from the dust. The increasing momentum for the manufacturing of functional products such as solar and flexible electronics could, therefore, see an increase in the use of carbon fibre rollers in order to increase yields.

Dr. Simon Hamblyn was born in Somerset, UK. He received a BEng degree in Mechanical Engineering in 1996 from Swansea University. This was followed by an MSc in Printing Technology and a PhD focused on ink transfer in Flexographic Printing. He spent over 16 years at the Welsh Centre for Printing and Coating undertaking collaborative projects with Multi-National companies and SME's in the printing and coating industry. He is currently a researcher and lecturer at the University of Applied Sciences in Leipzig, specialising in printing and packaging.

Prof. Dr. Lutz Engisch was born in Chemnitz, Germany. After his diploma study for chemistry including promotion, he attended different research projects in the printing sector at renowned institutes in Sweden and Australia. Before taking over the R&D department at SWG in 2008, Dr. Engisch was responsible for the digital printing department at the Institute for Printing and Media Technology (pmTUC) at the University of Technology Chemnitz.
In 2011, he was appointed professor for materials and materials testing in printing and packaging technics at the HTWK Leipzig.

Bibliography

[1] Smithers Pira, „The Future of Global Printing to 2022,“ 2017.

[2] S. C. Bushong, Radiologic Science for Technologists, Elsevier Health Sciences, 2013.

[3] F. Pursche, T. DePalmenaer und G. Seide, „Future directions and trends of the carbon fibre market,“ in *ECCM17 - 17th European Conference on Composite Materials*, Munich, 2016.

[4] D. Comand, „Low inertia carbon fibre rollers: a big step in the performance of coating, laminating and printing machines,“ in *AMICAL Conference*, Cascias, 2014.

[5] F. Rossini, „Concentric double sleeve for a rotary printing cylinder“. Patent EP0732201A1, 1996.

[6] A. Kückelmann, W. Brusdeilins, B. Steinmeier und W. Tappe, „Druckzylinder für Flexodruck“. Patent EP 1 808 293 A1, 2007.

[7] KBA, „Neo XD LR,“ 27 August 2018. [Online]. Available: https://www.koenig-bauer.com/produkte/flexo/ci-rotationen/neo-xd-lr/.

[8] F. Rossini, „Bridge sleeves with diametrically expandable stabilizers“. Patent PCT/EP2013/058971, 2016.

[9] K. W. Saueressig, „Engraved cylinder composed of a core and a detachable sleeve“. Patent EP0295319A1, 1991.

[10] R. M. Moss, J. W. Campion und S. R. Armfield, „Improved gravure printing rollers“. Patent WO2000059727A1, 2000.

[11] „ProROTO,“ Janoschka, 28 August 2018. [Online]. Available: http://www.janoschka.com/de/portfolio/d2/tiefdruck-sleeve/.

[12] V. Zschage, M. Mäser, L. Kroll, M. Klärner und J. Kaufmann, „Cylinder for a releasable connection with at least one working medium“. Patent DE102008018590B4, 2017.

[13] W. Pilath, O. Dax und P. Dilling, „Ink transport roller for the inking unit of a web-fed rotary printing machine and process for producing the roll“. Patent DE19628647A1, 1996.

[14] A. Jentzsch und U. Becker, „Farbheber für Druckmaschinen“. Patent DE4109438C2, 2001.

[15] H. Kohtz, „Inking unit of a rotary printing press“. Patent DE102005010302B4, 2008.

[16] KBA, „KBA C32 to C80: Productive high-performance web presses,“ 2012.

[17] A. Jentzsch und U. Becker, „Ink applying roller for rotary printing machine - is made from carbon fibre reinforced plastics to minimise weight“. Patent DE102008018590B4, 2001.

[18] J. Schölzig, „Coating device for printing or painting work in processing machine, comprises roller core formed from fiber composite material of carbon, where compressible layer formed from cellular foam material is adhered on roller core“. Patent DE102006037966A1, 2008.

[19] KBA, „KBA TR12B for web width of 14ft: Exploring a New Dimension,“ October 2003. [Online]. Available: http://whattheythink.com/news/5465-kba-tr12b-web-width-14ft-exploring-new-dimension/.

[20] H. Gruber, „Ultra-Leichtbau in der Papierindustrie,“ in *Automobil Industrie Leichtbaugipfel* , Würzburg, 2017.

[21] B. H. Gregory, Polyethylene Film Extrusion: A Process Manual, Trafford , 2009.

[22] A. Yoshiya, S. Shigemura, M. Nagai und M. Yamanaka, „Advances of thermal sprayed carbon roller in paper industry,“ in *Proceedings of the 2009 International Thermal Spray Conference*, Las Vegas, 2009.

[23] H. P. Degischer, „Innovative light metals: metal matrix composites and foamed aluminium,“ in *Materials & Design,Vol.18, Nos.46*, 1997, pp. pp. 221-226.

[24] „http://www.janoschka.com,“ 5 September 2018. [Online]. Available: http://www.janoschka.com/uploads/media/proROTO_download_DE.pdf. [Zugriff am 2012].

[25] D. Montalvão, A. M. R. Ribeiro, N. M. M. Maia, J. Duarte Silva und R. A. Cláudio, „Damping measurements on a carbon fibre reinforced laminate,“ in *International Conference of Noise and Vibration Enginneering (ISMA2006)*, Leuven, Belgium, 2006.

[26] Smithers Pira, The Future of Global Print Equipment Markets to 2021, 2016.

[27] R. Weis-Schiff, „Trends in innovations - flexible packaging,“ in *Image to Print*, Durban, 2018.

[28] M. Sullivan, „Printed Electronics: Global Markets to 2022,“ BCC Research, 2018.

[29] T. Long, „printinnovationasia.net,“ 2018. [Online]. Available: http://printinnovationasia.net/wp-content/uploads/2018/05/Thayer-Long-Trends-and-Opportunities-in-Global-Print.pdf.

[30] Statista, „Export value of books, publications and printing from India in FY 2015 and FY 2016,“ 2018.

[31] Smithers Pira, „Global Packaging Trends,“ 2017.

[32] DRUPA, „5th_Global_Trends_Executive_Summary_EN.pdf,“ www.drupa.com, 2018.

[33] „DAX Index,“ 27 August 2018. [Online]. Available: www.finanzen100.de.

[34] D. Yoon, S.-H. Lee, J.-S. Kang und B.-O. Cho, „Cantilever Type Idler Roller in Roll-to-roll Process for Printed Electronics,“ 2011.

[35] D. Lee, K. Choi und K. G. Bangjin, „Development of Composite Pressing Rollers for Thin Film Processing,“ in *Journal of Composite Materials 34(9):*, 2000.