Compounding Challenges for Vinyl Flooring

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Abstract

Luxury Vinyl Tiles (LVT) are the largest growing product group in vinyl flooring. The high-quality appearance combined with the ease of installation and maintenance results in a steadily growing demand. As more and more companies are entering the market, a broad variety of processing options evolved. The compounding processes are required to deal with higher line speeds on one side and higher expectations concerning process flexibility and higher economical pressure on the other side.

In the last years, more and more Continuous Kneaders are applied in this application. The unique principle of operation is used for all the different layers of the LVT. In the course of this talk we will investigate different options (with a focus on pelletizing and calendering processes) to deal with the demands of the market.

New developments concerning the addition of fillers into the compounding process applying Continuous Kneaders are investigated and compared to standard solutions. A significant increase of the line productivity can be achieved applying the newly developed intake system while keeping the screw speed of the Kneader screw at a very low level.

Introduction

One of the first major commercial applications of PVC was in the flooring sector (ref. figure 1). Since then the development of designs, materials, and processes continued.

Figure 1: Advertisement of PVC-Flooring displaying the Headquarter of Henkel in 1937. [1]

Figure 2: Application areas of PVC in EU28 in 2013 [2]

A broad range of materials are used beside vinyl, as there are ceramic floorings, carpets, laminates, wood and some other special flooring products. Even the vinyl flooring sector diversified significantly in the last 80 years. Products became more complex in design and much better in the appearance.

Taking a look at the shares in the vinyl flooring market (ref. figure 3), we can see that the market is well dominated by cushion vinyl (CV) products and luxury vinyl tiles (LVT). All forecasts say that that especially the LVT market will grow in the coming years, mostly taking shares from the laminate sector, which will result in an overall growth of the vinyl flooring market share.

Figure 3: Market shares in vinyl flooring. [3]

The reasons for the success of these products are due the high-quality appearance that can be adapted to customer’s needs and requirements. This becomes even more an advantage as it can be combined with the ease maintenance of PVC floors. Customers are more and more interested in products that can be tailored to their actual needs. This includes flooring products which look quite as natural products as stone, ceramics, or wood but requiring lower maintenance efforts. While this is basically true for most vinyl flooring products, LVT add the ease of...
installation (and ease of removal) to that list, which is the basis for the success.

Luxury vinyl tiles

While there is the fixed name “luxury vinyl tiles”, there is neither a single product nor a fixed construction of the flooring attached to it. Figure 4 shows an exemplary design of a LVT.

Figure 4: Exemplary design of a luxury vinyl tile.

Backing Layers

The backbone of the flooring tiles are the backing layers, which are reinforced by fibres. The layers are designed to give a good share of the requested properties on the final tile. Important properties comprise among others acoustical properties (noise damping) but also rigidity of the structure (ease to handle and install). Depending on the market quite soft structures are required (e.g. glue down products) or rather rigid structures are requested (e.g. tiles for free-flow installations).

The main filler in these backings are CaCO3 of different sizes, shapes and qualities. High filler contents (> 50wt.%) are state of the art. Current trends are aiming at even higher filling degrees to get increase stiffness (and more economically attractive) products. Further trends in material development involve alternative fillers and the increased use of recycling material.

Decorative Layers

The actual design of the tile is printed on the decorative layer. This layer contains colour pigments to give the optimal foundation for the printing. Thus, the requirement of the material is the good and fast reception of the paint, so the decoration can be placed accurately.

Currently mainly analogue printing technologies are applied, while most manufacturers have an eye on digital printing technologies which need to evolve in terms of quality and speed to be used in LVT applications. Nevertheless, digital printing is regarded as one of the essential progresses in the next years and will result in adapted formulations for the decorative layers. [5]

Wear Layers

Finally, the decorative layer is protected by a wear layer, which consists e.g. of a transparent PVC film. Main requirements are good wear properties and a good transparency to achieve best optical properties.

Alternative setups and production technologies

Still, there is a very large number of variations of the setup. The number of backing layers can vary. There might be a balancing layer to avoid curling of the tile. There can be further layers in the middle to adapt mechanical and economical properties of the tiles. Further there might be additional coatings to adapt the wear behaviour. Beside the actual design, there are numerous ways to in the design of the individual layers of the tiles. Krebber4 gives an overview of different options of the setup and production technologies of LVT. The broad variety results in some challenges for the compounding equipment manufacturers as they need to provide equipment which are at the interface of the different formulations and processing technologies.

Summary of Compounding Challenges

The challenges a compounding machine manufacturer has to face are related to:

- the different processes involved in the manufacturing (offline pelletizing; online calender feeding).
- the trends in material/formulation development, involve high contents of fillers. Further there is an increasing interest in new fillers, which sometimes show difficult material handling behavior.
- the need to use recycling,
- and finally, the overall requirement in LVT business: higher productivity of the production lines and an increasing demand in flexibility.

Of course, these challenges need to be met at the same time. A broad range of compounding systems are available to deal with these challenges (ref. figure 5). All systems have their distinctive strengths. Schuler [6] compared these systems and summarised their characteristics and features.

Especially the combination of excellent mixing performances with low energy input by dissipation makes Continuous Kneaders a very popular choice to prepare PVC compounds for LVT.
X-Compound Continuous Kneader

During World War II, a group of engineers at the company IG Farbenindustrie (now Bayer, Covestro) was assigned to invent new continuous equipment to replace batch processes, especially for highly viscous products. The most famous members of this group used to be Mr. Erdmenger, who invented the co-rotating twin screw extruder, and Mr. List, who invented Continuous Kneaders. The patents for both machines were sold to designated machine manufacturers after the war and got spread after the patents expired. The first commercial Continuous Kneaders were presented right after the war in 1946 in Basel, Switzerland.

Working Principle

The special characteristic of Continuous Kneaders is the unique working principle, as the Kneader screw oscillates and rotates at the same time (ref. figure 6). Another important feature of this types of machines is the modular setup (ref. figure 7). Special attention need to be paid to the interaction of the kneading teeth and the screw elements.

Figure 6: Superimposition of oscillation and rotation of the Kneader Screw

As the screw rotates and oscillates at the same time, the kneading teeth wipe the screw flights. Thus, there are virtually no dead spots, where the material can stagnate and decompose.

Figure 7: Modular Setup of the processing section

This self-cleaning feature can be easily observed by following a kneading bolt as it marks a path of the Kneader screw. If all bolts are assembled and the paths are drawn at the same time, the picture as it is shown on figure 8, right, appears and shows no stagnation regions of the screw.

Figure 8: Paths of the kneading teeth

Figure 9 shows the main mixing effects of Continuous Kneaders. A volume element of the material is separated due to the teeth – screw flight interaction and reunited afterwards. A behavior well known as “stretching and folding”. In the course of this process, the material is exposed to stress and shear as it passes the clearance between the screw flight and the teeth.

Figure 9: Mixing behavior of Continuous Kneaders

One approach to evaluate the “stretching and folding” performance is the theoretical calculation of striation thicknesses. The basic idea behind this measure is, that in a system of an inner and an outer barrel, where the inner barrel rotates, two components might mix just because of the rotation of the inner barrel. As the rotation continues a more and more homogeneous mixture is achieved (ref. figure 10).

Figure 10: Evaluation of mixing by calculation of the striation thickness
In case of Continuous Kneaders the calculation to the striation thickness would be:

\[ s_{\text{LK}} = s_0 \cdot 2^{-i_{\text{FK}}} n_{\text{KS}} \]  

where \( i_{\text{FK}} \) states the number of interactions between flights and teeth at the length of one stroke of the Kneader, and \( n_{\text{KS}} \) is the screw speed. Due to the large number of interactions, the thicknesses of the individual layers decrease rapidly and are the reason for the relative short lengths of the processing section required in case of the Continuous Kneaders.

The dispersion of fillers depends beside the distributive mixing performance on the shear forces imposed onto the material. This shear rate can be calculated according to equation (2).

\[ \dot{\gamma} = \frac{v}{s} = \frac{a \cdot b \cdot n_{\text{KS}}}{s} \]  

The power introduced into a volume element of the polymer can then be calculated using equation (3)

\[ P = \eta \cdot \dot{\gamma}^2 \cdot V \]  

It needs to be mentioned that the clearance \( s \) is quite large compared to other compounding machinery. The shear rate and thus the power consumption is much lower and on an intermediate level.

**Incorporation of highest filler contents**

As mentioned above, higher and higher contents of fillers are to be incorporated into the compounds to adjust mechanical and economical properties. As these high filler contents are not that economical to be incorporated in the heating-cooling mixer units, this is the task of the Continuous Kneader. In former processes, it was observed that frequently the feeding of the filler became a limiting factor. This means that it was only possible to feed a certain amount of CaCO3 into the Kneader. As the torque was on a low level, it is obvious that the available volume was the limiting factor. To overcome these limitations, a modified intake section was designed (ref. figure 12).

The increased volume makes it possible to overcome these limitations as shown in figure 13. It can be seen that the output per rotation for the traditional system is limited to approx. 2.7 kg min/h. The introduction of the higher volume intake overcomes this limitation and exceeds now easily 3.1 kg min/h, which is an output increase of more than 14%.

**Flexibility**

The compounding line itself has a tremendous flexibility concerning its setup. A broad range of process parts are available to adjust the setup to the process requirements. Beside the optimum setup of the line itself, there are needs for a significant flexibility in processing.
Calender feeding lines need to operate at different speeds depending on the requirement and demand of the calender. This different speeds represent the operation window within the calender feeding line has to deliver a uniform and reproducible quality stock.

For instance, stock temperature variation over the whole speed band is acceptable within a narrow window only to avoid influence to the performance of the calendering process and quality of the film. During start up the speed of the calender feeding line is typically low and will gradually be increased until full capacity. For the whole production time the calender feeding line has to follow the calender speed. Different density and thickness of film combined with the individual production window results in a capacity window of the calender feeding line.

Continuous Kneaders are outstanding as high turndown ratios in a range up between 5:1 and 9:1. This is possible as the main energy intake is in the shear gaps between the kneading teeth and the screw flights. The combination of this special way to introduce the energy and the quite low screw speeds makes it possible to achieve both a good plastification of the PVC at low outputs and a moderate temperature at high outputs.

**Conclusion**

The demand for high quality, easy to maintain floors is steadily growing. The market with the highest growth rates are Luxury Vinyl Tiles (LVT), which combine an appealing look with the ease of installation and maintenance. Especially the possibility to produce almost any kind of design serves the trend to more individual products. To achieve the desired properties different companies choose several ways to setup their flooring product. When it comes to the preparation of the materials, the trends and needs can be summarised as follows:

- The compounding process needs to be able to produce high quality pellets if used as an offline process or needs to be able to deliver high quality materials to calenders at a broad range of outputs (high turndown ration necessary).
- As the products become more and more common, there is an increasing demand in differentiating products. One way is the adjustment of the mechanical properties from very soft to very hard flooring products. Thus, the compounding process needs to be able to deal with highly filled materials as well as with compounds that contain not so much filler.
- The production needs to become more and more efficient. This is achieved on the material side by using recycling materials, e.g. from internal sources, and higher filler contents (see above), and by using equipment that shows low wear and a design that allows for quick maintenance and process adaptions.

Continuous Kneaders prove their ability to meet these requirements, showing a high flexibility, the possibility to incorporate highest filler contents at low wear rates.

**References**

4. J. Krebber, Conference Proceedings Polymers in Flooring; AMI Conference, 06.-07.12.2016, Berlin, Germany
5. Panel discussion at Conference Polymers in Flooring; AMI Conference, 06.-07.12.2016, Berlin, Germany
Table 1: Comparison of continuous compounding systems (modified based on [6])

<table>
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<th>Single Screw</th>
<th>Co-Rotating Twin Screw</th>
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