LIQUID COATING METHOD AND APPARATUS WITH A DEFORMABLE METAL ROLL

TECHNICAL FIELD

The present disclosure relates to methods and apparatus of applying a liquid coating to a substrate by using a deformable roll including a thin metal shell.

BACKGROUND

Numerous industrial and consumer products include an aspect of coating in their manufacture in which one or more layers of liquid material are deposited onto a discrete object or onto a thin web of material of indefinite length being conveyed through a web path. It is frequently desirable to convey such a web at as great a speed as practicable through the web path in order to minimize the cost of production.

SUMMARY

Briefly, in one aspect, the disclosure describes a method including providing a first roll, a second roll, and a nip formed between the first and second rolls, supplying a coating liquid to the nip, and smoothing the coating liquid, via the nip, into a substantially uniform layer of liquid coating. The first roll includes a thin metal shell and a resilient layer, the thin metal shell encases the resilient layer therebeneath, and the thin metal shell is capable of deflecting in unison with the resilient layer such that the thin metal shell is elastically deformable at the nip when in contact with the second roll. The layer of liquid coating is transferred to a substrate. In some embodiments, the liquid coating is applied to a web of indefinite length material.

In another aspect, this disclosure describes a coating apparatus that includes a first roll including a thin metal shell and a resilient layer. The thin metal shell encases the resilient layer therebeneath, and the thin metal shell is capable of deflecting in unison with the resilient layer. A second roll forms a nip with the first roll such that the thin metal shell is capable of being elastically deformed at the nip when in contact with the second roll. A liquid delivery system is disposed to supply coating liquid into the nip.

Various unexpected results and advantages are obtained in exemplary embodiments of the disclosure. One such advantage of exemplary embodiments of the present disclosure is that a very thin (e.g., no greater than 5 microns, or even no greater than 2.5 microns), continuous liquid

coating can be transferred to a substrate with controlled defect levels such as ribbing defects discussed below.

Ribbing defects are often observed in conventional roll coating processes for liquid coatings, for example, when the coating liquid has a viscosity of about 0.1 mPa·S or greater. The defects may occur as a coating liquid passes through a nip between rolls and the viscous stress at a film split overcomes surface tension forces attempting to maintain a uniform curvature of the interface at the film split. The balance of viscous to surface tension forces can be described by a dimensionless capillary number defined by the equation $Ca = \mu U/\sigma$, where Ca is the capillary number, μ is a liquid viscosity, U is an average speed of the first and second rolls, and σ is the liquid surface tension. The ribbing defect may lead to a highly non-uniform coating as the liquid exits the nip. While this may be a tolerable coating defect if the ribs or ribbing defects are able to level when line speeds of the rotating rolls are low, it can limit line speeds, reduce the coating efficiency, and increase the cost of production. Additionally, as line speeds are increased it can lead to misting, for example, ejection of small droplets in the form of a mist as the ribs pass through the nip, which can be a concern for the health and safety of the factory environment.

In some embodiments described herein, the above ribbing defects in liquid coatings can be impacted, altered, or adjusted by placing a thin metal shell on the outside of a deformable roll having an underlying resilient layer. The mechanics of deformation of the roll surface at the nip may be significantly altered, leading to a change in the pressures developed in the nip, and hence to a change in the character of the ribbing instability. In some embodiments, liquid coating methods are provided that can substantially decrease the number of ribs present in a liquid roll coating nip, for example, a forward roll coating nip, for a given line speed above a critical value of the capillary number, for example, about 0.1 dimensionless units or greater.

Additionally, in some embodiments, roll coating of thin liquid layers onto a substrate may require the use of at least one deformable roll in the nip to provide improved uniformity at a low enough flowrate to achieve the target caliper, which would require increasingly perfect steel rolls in a rigid system. This deformability is typically achieved with rubber rolls, which are susceptible to damage and wear during operation in the absence of a thin metal shell. Such damage and wear can negatively impact the coating quality. The damage or wear can come from sources as benign as substrate splices and edges, especially when operating at high speeds. By covering the resilient layer with a thin metal shell, the durability of the roller is dramatically improved, without affecting the ability to deform the roll and achieve thin coatings.

Listing of Exemplary Embodiments

Exemplary embodiments are listed below. It is to be understood that any one of the embodiments 1-15 and 16-24 can be combined.

dimensions. For example, the resilient layer 30 may be slightly oversized and the thin metal shell 40 may be slightly undersized. When the resilient layer 30 is pressed into the thin metal shell 40, the resilient layer 30 may elastically deform slightly to generate an interference fit with the thin metal shell 40. In some embodiments, temperatures of the mating parts, i.e., the resilient layer 30 and the thin metal shell 40, may be controlled to utilize the different thermal properties (e.g., thermal expansion or contraction) of the respective materials (e.g., metal versus rubber). In some embodiments, the contacting surfaces of one, another, or both of the mating parts may be textured to improve the interference fit.

In some embodiments, the use of an interference fit between the resilient layer and the thin metal shell, however, may create challenges due to the nearly incompressible nature of most elastomeric rubber coatings. This nearly incompressible nature means that any mass of rubber that is displaced from one location must migrate to another location, and so in the context of the fit between the resilient layer and the thin metal shell will result in slippage of the thin metal shell over the resilient layer. This challenge can be overcome by using a compressible resilient layer, such as a foam, or by placing grooves in more typical elastomeric rubber to give the displaced rubber a place to go, and make an effectively compressible resilient layer.

In some embodiments, the thin metal shell 40 can be removably mounted onto the resilient layer 30 with an interference fit via any suitable assembling processes. For example, the temperature of the assembly of thin metal shell 40 and resilient layer 30 may be controlled to adjust the dimensions of the mating parts so as to allow the thin metal shell 40 to slide off the resilient layer 30 without damaging the mating parts.

In many embodiments, methods and apparatus described herein can be applied to form thin liquid coatings on a substrate. In a liquid coating process, a common means of applying a liquid onto a moving substrate is through a class of coating techniques known as roll coating. This class includes methods such as, for example, direct roll coating, reverse roll coating, forward or reverse offset roll coating, five roll coating, and many other variants. While there are differences between all of these methods, the common tie is the formation of one or more nips between adjacent first and second rolls, and optionally a web wrapped around the first or second roll. A coating liquid is supplied to the nip using a liquid delivery system, after which the coating liquid passes through the nip and undergoes a film split, resulting in some coating liquid on both the first roll and the second roll. A deeper discussion of the various types of roll coating and their underlying physics can be found in literature such as Coyle (PhD thesis, University of Minnesota, 1984), Benjamin (PhD thesis, University of Minesota, 1994), and Carvalho (PhD thesis, University of Minnesota, 1996).

Ribbing defects may occur as a fundamental coating defect in conventional rubber roll coating systems when a liquid passes through a diverging gap, which results in a highly non-

uniform coating as the liquid exits the nip. Because this is a viscous effect, it is governed by a capillary number, $Ca=\mu V/\sigma$, where μ is the liquid viscosity, V is the average speed of two rotating rolls (i.e., line speed), and σ is the interfacial tension of the liquid. Ribbing defects may be observed when the capillary number becomes greater than a critical limit, for example, when the line speed of process rises above a critical value for given coating materials (e.g., a coating liquid). Further increases in the line speed above the critical value may increase the frequency of the ribs produced, and eventually can lead to the ejection of small droplets in the form of a mist as the ribs pass through the nip. Not only can this mist affect the product quality, but it is also an environment, health and safety concern. Thus, the above ribbing induced problems may significantly limit the line speed for conventional rubber roll coating systems and methods when applying a liquid coating to a web.

This disclosure describes apparatuses and methods of liquid roll coating where a first roll includes a thin metal shell and a resilient layer, the thin metal shell encases the resilient layer therebeneath, and the thin metal shell is capable of deflecting in unison with the resilient layer such that the thin metal shell is elastically deformable at the nip by contact with the second roll. It is to be understood that the construction of the first roll including the thin metal shell and the resilient layer disclosed herein could be applied equally well in variants of roll coating listed above, e.g., direct roll coating, reverse roll coating, forward or reverse offset coating, five roll coating, or any other roll coating methods.

The methods and apparatus described herein can impact, alter, or adjust the above ribbing defects by using a deformable roll including a thin metal shell such as, for example, the second roller 16 shown in FIGS. 1 and 2, especially when the line speeds of the rolls are in a relatively higher speed region. In some embodiments, application of a thin metal shell to a roll coating system can fundamentally alter characteristic behavior of ribbing, resulting in a much more uniform liquid coating compared to conventional rubber roll coating systems and methods.

In some embodiments, the line speeds of the rolls can be determined based on the properties of a given coating liquid, and the first and second rollers 14 and 16 of FIG. 1 can be rotated in contact with each other at the predetermined line speed with a diminished impact from the ribbing defects. For example, the predetermined line speed and the viscosity of the coating liquid are such that the corresponding capillary number Ca for the coating can be controlled to be greater than a critical value. Above the critical value, using a thin metal shell such as in some embodiments described herein can significantly reduce ribbing defects as compared to conventional rubber roll coating systems and methods. In some embodiments, the critical value can be, for example, no less than 0.01, no less than 0.02, no less than 0.05, no less than 0.1, or no less than 0.2. The critical value can be, for example, no greater than 100, no greater than 10, no greater than 2, or no greater than 1. A typical critical capillary number for ribbing-style defects