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Modelling of ink tack property in offset printing

Introduction

Offset ink tack is a property related to its adhesion and cohesion, representing the force required to separate the layers of ink between the form and the blanket (or blanket and substrate) in the printing press. This force can vary, depending on various parameters [7, 11], in particular the ink temperature and the printing speed. This indicates a relationship, but not identity, to the viscosity of ink. Since the distribution of ink between the cylinders of an offset press is one of the phenomena that characterize offset printing [7], all the factors affecting this phenomenon has long been the subject of research and analysis. A simplified Walker-Fetzko model cited in [7] describing the ink split between the form/blanket and the substrate (absorptive) dates from 1955, however it does not address the rheology of ink.

In Polish literature a parallel concept of "stickiness" was sometimes used, which clearly indicates the ink tack relates to adhesion and cohesion, similarly to adhesives.

In the literature one can find many papers, which explore the impact of ink tack on various phenomena related to printing, as well as the emergence of printing faults. Especially interesting are papers which call attention to the problems arising from the cohesion, and thus tack, of the offset printing inks. These include for example [3, 8], which assess the impact of the tack on linting in offset printing, or [17], which, in turn, examines the problem of delamination of composite materials (such as cardboard) during printing. On the other hand, it is possible to analyze the impact of the ink tack on the release of sheet in the offset printing press, which was made in the article [10] in order to optimize the production of substrates.

A relationship between tack and other print faults, in particular misting, is well known [15], and in most cases misting is ascertained using a device which measures ink tack value. The effect of ink tack on print quality is discussed for example in [6]. It appears that ink tack appears as a parameter in a number of relationships associated with the printing process.

At the same time, however, there is no clear definition of offset ink tack [9, 12], and thus it is difficult to determine how to use it in the calculations and numerical models. Both the tack concept and its measurements are defined in various ways. Article [9] cites the following definitions of tack:

- a resistance which a thin ink film offers against fast splitting under certain conditions (Mewis, 1967);
- a drag force between two rotating roller caused by the presence of an ink layer on their surfaces (EAIPM, Technical Committee for Group of Printing Inks, 1974);
- a restoring force between two rotating rollers of a given width caused by the splitting of an ink or vehicle film on the roller surfaces (ISO 12634:1996. Graphic technology – Determination of tack of paste inks and vehicles by a rotary tackmeter);
- a function of the force required to split a thin fluid film of a printing ink or vehicle between two rapidly separating surfaces, which is a rheological parameter indicative of internal cohesion of the fluid (ASTM D 4361-97 Standard for tack measurement).

Still other definitions of tack (partly coinciding) are mentioned in [18], while discerning several forms of tack; ink tack is then described as a cohesive tack.

It is evident that there is a discernible discrepancy in these definitions, since tack is defined once as the resistance force of the ink, and otherwise as the force acting on the machine elements (rollers). Probably the last definition is the most accurate [9], as it indicates that the tack is a function of the force required to split the ink, being a rheological parameter that is associated with the ink cohesion. At the same time, it does not specify how to measure the tack, which would be required for the definition to be comprehensive.

Therefore, it was considered necessary to analyze the available tack models which define the tack as physical ink property.

Different models of tack as a physical property

In most U.S. papers ([2, 16]), the tack is considered to be the force required to split a thin layer of fluid (i.e. ink) between two rapidly moving surfaces (cylinders), which can be described by the Stefan equation (however it is relating to the force required to separate two parallel plates immersed in a liquid [16]), of the form:

$$F = \frac{\eta V A}{h^3} \tag{1}$$

where F – splitting force
η – dynamic viscosity of the liquid
V – separation velocity (a relative movement speed between two plates)
A – plate area (contact zone area)
h – distance between plates (ink layer thickness).

A dimension of the resulting equation is $[ML^{-1}T^{-1}LT^{-1}L^2L^{-3}] = [ML^{-1}T^{-2}]$, i.e. [force/area], thus equal to tension. For that reason, the Stephan equation must be considered to describe a splitting force for the unit of separated area.

The model also shows that this force will decrease with increasing ink layer thickness, in proportion to the third power, and will be directly proportional to the speed of separation and surface contact area. It should be noted that this means the linear dependency on force and the rotational speed of the cylinders.

This model, and a similar Stefan-Reynolds theory, which assumes that the force required to separate the two disks immersed in the ink is proportional to the fluid viscosity and inversely proportional to the square of the thickness of the ink layer, is sometimes [15] is used to measure the ink tack.

Shakhkeldian [15], followed by Jakucewicz [5], describes the ink tack phenomenon as a hydrodynamic problem of a cylinder, rolling uniformly along the plate (surface) covered with ink layer. This model is presented in the Figure 1. The force *Q* applied to the cylinder is the result of the horizontal component of the hydrodynamic forces (normal and tangential to the surface of the cylinder), which oppose the rotation of the cylinder. This model assumes that the cylinder is of infinite length and the its weight per unit length is *q*. This weight (cylinder pressure) is balanced by the vertical component of the resultant hydrodynamic forces. It is also assumed that the parameters of ink (in particular its viscosity) remain constant regardless of the acting forces.

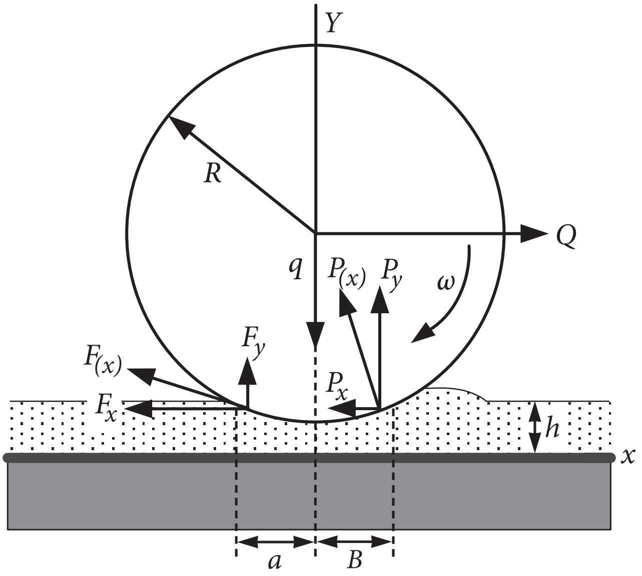

Figure 1. Ink tack forces as a result of hydrodynamic processes [15]

The approximate model showing the relationship of the force *Q* and ink properties as well as process geometry is given by [15] and subsequent authors as

$$Q = 1.5 \cdot (\eta\omega R)^{0.75} \left(\frac{h}{R}\right)^{0.75} q^{0.25} \tag{2}$$

where η is the dynamic viscosity of the ink.

Under these conditions, the force *Q* is related to the unit length of the cylinder, and thus has the dimension [N/m] = $[MT^{-2}]$.

Shakhkeldian [15] also indicates that the ink split between the rollers creates a new surface, and according to the Dupre theory this requires the application of force opposing the cohesion of the ink, resulting in execution of work by this force, acting on the distance of reach of the molecular forces. This work (referred to 1 m^2 of the newly-formed surface) is equal to the free energy of the formed surface, i.e.,

$$A = 2\sigma \tag{3}$$

where σ – surface tension of the ink.

Experiments show, however, that the work carried out during the separation of ink layers is larger than the result of cohesive forces only [15], which indicates that the Dupre theory does not necessarily explain the process of ink splitting between the rollers. The literature indicates also that it is possible to describe this phenomenon based on Maxwell's theory of elasticity, assuming that the ink split between two rotating rollers creates a number of ink threads which act as a spring.

Regardless of the theory, however, it is apparent that the measure of the force required to separate the layers of ink may ultimately be the work that is necessary for this separation, relative to the unit area. Thus, the physical dimension of tack if understood in this way is [J/m^2] = [MT^{-2}].

In [14] ink tack determination consists of measuring the work required to separate the ink layer on the surface of 1 cm^2. This work can be determined on the basis of extending a spring of known stiffness, which is attached to the roller of known area, rotating in contact with a polished cylinder with an ink layer between them. This measurement scheme corresponds almost exactly to the model outlined above, except that the roller has known, finite length, and the force F is determined by the product of the spring stiffness coefficient and its elongation. Such an approach assumes, therefore, that the physical tack dimension is [J/m^2] = [MT^{-2}], which also corresponds to the above model.

Methods of ink tack measurement

Ink tack can be measured only in an indirect way [12], and the simplest methods used by the printing machine operators are the reference methods. They rely on the observation of the behaviour of ink dripping from the filler or spatula[11]. An ink with low tack forms long strands, and a high tack ink – short strands that quickly break. Hence the term "long" or "short" ink is used. Similar comparisons can rely also on the observation of ink behaviour between one's fingers, or by touching an ink drop on a flat surface and observing its behaviour when lifting the finger. These methods provide a qualitative assessment only and can only be used by an appropriately experienced press operator.

Quantitative determination of ink tack requires another physical quantity measurement, which is affected by tack. In [12] four methods of measurement are identified, involving the measurement of:

- force required to peel off an adhesive tape from the layer of ink / glue on the known area;
- force required to move the loop of self-adhesive tape at a constant speed that is pressed against a coat of ink or glue (typically used to assess the adhesive

properties of self adhesive paper), thus the property measured is sometimes called the "loop tack" [12, 18];
- force required to lift a rod of known surface roughness and face area which is initially pressed to a layer of ink/glue;
- stopping distance of the balls with known parameters rolling along the inclined surface covered with ink/glue.

In addition [12], measuring instruments developed specifically for this purpose are used. For adhesives and self-adhesive substrates, these measurement methods are standardized, or normalized (7 national and international standards mentioned by [12] and [4]). The same methods are described in [18].

In printing applications, the simplest ink tack measurement methods are based on measuring the braking torque resulting from the ink split between the rotating rollers of the device. The first such device (inkometer) was constructed in 1938 [11], where a braking torque was produced by manually moving the counterweight. Currently available devices of similar construction (trade names: Tackometer, Inkometer, Tack-O-Scope) usually measure the torque electronically. These devices are therefore scaled in units of torque (force · length). A small number of devices (e.g., Kershaw Instruments Tackmaster 72) are calibrated in other units (force /length).

Still other devices (e.g., Pruefbau Deltack) measure the force of the ink split and its change over time [13] by measuring the force on the sensor inside the measuring roller, and are directly calibrated in units of force.

The values obtained by measurements in this way are dependent on the rotational speed of the cylinder and the temperature [11]. Therefore, for comparing the measured values of ink tack it is necessary to determine both of these parameters. Some measuring devices, therefore, control the temperature of the rollers used.

Another method mentioned in [9] and [10] consists in measuring the force, which is required to lift the rod of known cross-section, pressed into the ink sample. This method has been used in MicroTack device [10]. Another method described in [14] consists in measuring the force acting on the roller covered with ink, and the spring displacement by this force, i.e., the work done by forces of cohesion.

The above data indicate that there is no direct way to compare the numerical value of tack as a physical quantity, both because of lack of a uniform definition, as well as the different accepted methods. Moreover, it is assumed [11] that the tack is expressed in arbitrary units, which do not have direct physical meaning. As a result, in the papers discussing ink tack and its influence on the printing process, there are different scales related to the equipment used, for example, in [3] and [13] tack is measured in the units of force (in Newtons), in [6] is measured as the force per unit length (in g/m, or correctly G/m), and in [10] and [11] tack is in dimensionless units. This corresponds to using devices Pruefbau Deltack, Tackmaster and Tack-O-Scope devices accordingly. In some studies it was assumed that the ink tack measurement shall provide the type of device used (e.g., 110–150 [Tack-O-Scope]). According to [9], it is possible to convert the tack value measured by various methods, provided that:

- the thickness of ink layer used for measurement is not less than 10 μm;
- the rubber roller hardness for each measuring instrument is comparable;
- the measurements show a clear dependence of tack on different rotation speed of the rollers.

Taking into account the fact that the ink tack is an important factor in the offset printing process, it was considered appropriate to provide an analysis which may help how to consider its physical nature, i.e., determine its physical dimension. Since the tack models differ, it is assumed that the analysis will be provided for the model first described by Shakhkeldian in 1975.

A dimensional analysis of Shakhkeldian tack model

According to the model assumptions [15] (see Figure 2), the force *F* relates to the ink properties and process geometry as follows:

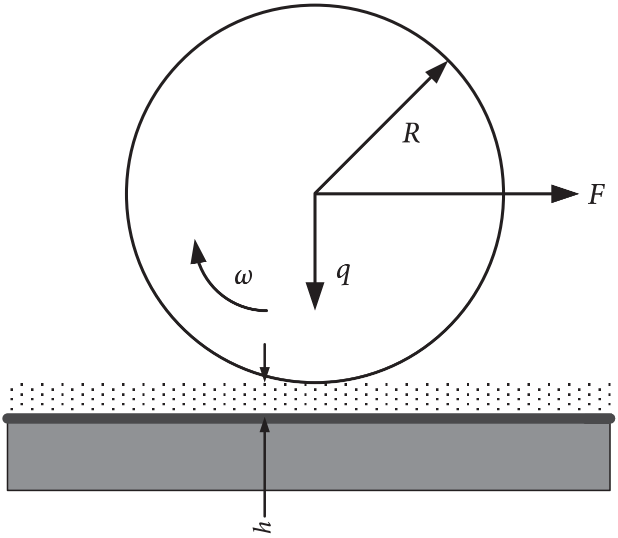

Figure 2. A simplified tack model for dimensional analysis

$$F = 1.5 \cdot (\mu \omega R)^{0.75} \left(\frac{h}{R}\right)^{0.75} q^{0.25} \tag{4}$$

where μ – dynamic viscosity of the ink.

The force *F* is related to the unit length of the cylinder and has a dimension of [N/m] = $[MT^{-2}]$. Similarly, the dimension of the q force (pressure/weight of the cylinder) is the same.

The following discussion will show that the above equation is valid, by considering a way to find the form of the relationship $F = f(h, R, \omega, \mu, q)$.

The physical dimensions of the factors appearing in the above relation are as follows:

Table 1. Physical dimensions of the properties used in the model

Property	SI unit	Dimension
F	N/m	MT^{-2}
h	m	L
R	m	L
ω	1/s	T^{-1}
μ	Pa·s	$ML^{-1}T^{-1}$
q	N/m	MT^{-2}

where M – mass, L – distance, T – time

From the Buckingham Pi Theorem [1] we may find that for 5 independent parameters of the relation that use 3 basic dimensions, a corresponding dimensionless formula shall use 2 dimensionless similarity numbers.

Assuming that the relation $F = f(h, R, \omega, \mu, q)$ can be expressed as a product of power monomials, one may write it as

$$F = c \cdot R^A \omega^B h^C \mu^D q^E \tag{5}$$

By analyzing the dimensions of this we get:

$$\mathrm{MT}^{-2} = \mathrm{L}^A\,\mathrm{T}^{-B}\,\mathrm{L}^C\left(\mathrm{ML}^{-1}\mathrm{T}^{-1}\right)^D\left(\mathrm{MT}^{-2}\right)^E \tag{6}$$

i.e.

$$\mathrm{MT}^{-2} = \mathrm{M}^{D+E}\,\mathrm{L}^{A+C-D}\,\mathrm{T}^{-B-D-2E} \tag{7}$$

For the dimensions of both sides to be equal, the following relations must be satisfied:

$$D + E = 1$$
$$A + C - D = 0$$
$$-B - D - 2E = -2$$

therefore one may find that

$$D = 1 - E$$
$$A = D - C = 1 - E - C$$
$$B = 2 - D - 2E = 2 - 1 + E - 2E = 1 - E$$

Considering that, we get

$$F = c \cdot R^{1-C-E}\,\omega^{1-E} h^C\,\mu^{1-E} q^E \tag{8}$$

which gives the equation

$$F = c \cdot \mu\omega R \left(\frac{h}{R}\right)^C \left(\frac{q}{\mu\omega R}\right)^E \tag{9}$$

or in the dimensionless form

$$\frac{F}{\mu\omega R} = c \cdot \left(\frac{h}{R}\right)^C \left(\frac{q}{\mu\omega R}\right)^E \tag{10}$$

In this manner, the relationship of the rolling force required to move the cylinder along the ink layer and the process parameters is found, using the dimensionless numbers and containing three unknown constants.

This equation may also be rewritten as

$$F = c \cdot (\mu\omega R)^{1-E} \left(\frac{h}{R}\right)^{C} q^{E} \tag{11}$$

which thus gives the formula used in [15], provided that $c = 1.5$, $C = 0.75$, $E = 0.25$.

Considering that $\omega R = V_r$ (cylinder peripheral speed), the formula can be written as

$$F = c \cdot (\mu V_r)^{1-E} \left(\frac{h}{R}\right)^{C} q^{E} \tag{12}$$

or even

$$F = c \cdot (\mu V_r)^{1-E} \left(\frac{h\omega}{V_r}\right)^{C} q^{E} \tag{13}$$

From the equation it is certain that (assuming a positive value of the exponents C and E), the force will increase with the increasing of ink film thickness and with an increase of pressure (weight). Similarly, increasing the angular velocity of the cylinder will increase the force required to separate the ink layers. This is consistent with experimentally confirmed (for example in [15]) dependency of ink tack on the roller rotational speed in the actual measuring device. It should be noted that the relationship is not linear, as it would appear from the Stefan equation. Analysis of the graphs shows that the model described by Shakhkeldian is much closer to the results obtained.

Conclusions

The analysis showed that the formula defining the force necessary to overcome the resistance of the ink resulting from its cohesion (i.e. ink tack as defined by ASTM), that was quoted for the first time by Shakhkeldian and repeated by other authors, may suggest that the ink tack is a physical quantity whose dimension is [J/m^2] = [MT^{-2}]. Simultaneously, tack measurements using specialized devices reveal that the character of this model correlates well with the measurement results. The results found in the literature do not correlate with Stefan equation due to the linear dependence of the separation force on the splitting velocity.

Based on the analysis of the ink tack models used and theories used to describe ink distribution process it can be concluded that the best way for the quantitative measurement of tack is the work required to split the ink between two moving surfaces, referred to the unit area. It is also consistent with the perception of tack as a phenomenon resulting from the ink cohesion.

In view of the various construction and the choice of various physical quantities measured in the devices, one cannot determine a single value for the given ink tack. However, available data suggest that under certain conditions there is a high and reproducible correlation between the results achieved using a variety of devices, suggesting that it is possible to develop a single tack scale, regardless of the equipment and measurement methods.

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Streszczenie

Modelowanie własności tacku farby w drukowaniu offsetowym

Tack farby jest jedną z istotnych właściwości farby offsetowej, która ma znaczący wpływ na proces drukowania. W dostępnych pracach badawczych (Mangin i Silvy, Gujjari i in., Jasurek i in., Mattila i Passoja) wykazano duży wpływ tacku na zjawiska zachodzące w czasie drukowania oraz jego związek z powstawaniem niektórych wad druku. Jednocześnie zarówno samo pojęcie tacku farby, jak i sposób wyznaczania jego wartości, nie zostały jednoznacznie zdefiniowane (Massolt, Roberts). W niniejszej pracy przeanalizowano proponowane modele tacku farby i przeprowadzono analizę wymiarową zagadnienia, która pozwala uzasadnić stosowanie popularnego w literaturze wzoru wiążącego tack z lepkością farby i geometrią drukowania. Przeprowadzono jednocześnie dyskusję dotyczącą różnych modeli tacku (np. opartych o wzór Stefana) i ich wpływ na rozumienie tacku jako wielkości fizycznej. Stwierdzono, że model zaproponowany przez Szachkeldiana, wykorzystujący zjawiska hydrodynamiczne do określenia pracy wymaganej do rozdzielenia warstw farby, jest dobrze dopasowany do eksperymentalnych wyników pomiaru tacku. Stąd, zakładając, że tack farby jest powiązany z jej kohezją, najlepszym sposobem oceny takiej wielkości fizycznej w odniesieniu do farby jest pomiar pracy jednostkowej wykonanej przy rozdzieleniu warstw tej farby. Praca omawia również wiele metod pomiaru tacku i na podstawie zebranych danych określa także, w jakich warunkach możliwe jest porównanie wyników pomiarów wykonanych różnymi metodami i przy użyciu różnych urządzeń. Pozwala to na lepsze zrozumienie tacku jako zjawiska, jak też lepsze wykorzystanie tej właściwości farby do modelowania procesów drukowania oraz w metodach kontroli jakości.