Runnability in Digital Package Printing

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Abstract: Digital printing is a fast growing technology and several paper qualities have already been developed for this application. Digital package printing is on the other hand a rather new area, but a probable prediction is that there soon will be a market need for board products that can be used for digital printing. Because of future requirements, it is very important for the packaging industry to gain knowledge about the interaction between the substrate and the press, especially when it comes to runnability.

This study reports on a runnability test on five different highly topical print units and ten different substrates. The print units were based on both electrophotographic technology and liquid toner technology and all printers except two were sheet fed. In order to attain a broad study, three different types of board were used; coated liquid packaging board, craft paper for sacks and coated graphical board and finally a commercial paper for digital printing as benchmark.

Results shows that sheet fed printers have a low acceptance for curl and deformed sheets. Well cut sheets, right thickness and opacity is also very important in this context. When it comes to runnability in the web fed printer, problems often occurs in the cutting unit.

Introduction

Digital printing is a print technology that eliminates steps like films and plates. It also makes it possible to produce small editions for a low price and the opportunity to vary every single print with text or pictures. The main principle for a digital press is a direct transfer from computer to press. Photoconductive drums for each process color are charged and the printable areas are exposed with either a laser beam or a LED-array. The exposed areas that get a different charge than the none-printable areas attract toner. After the application of toner the subsequent printing steps depend on whether it is dry or liquid toner.

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The dry toner technology (electro photography) transfers the toner directly to the substrate with the help of a charged corona wire, while the liquid toner technology first transfers the liquid toner to a warm rubber blanket and then to the substrate. The liquid toner technology does not need any further step to fix the toner onto the surface, but the electro photographic technology needs a fuser with heat and/or pressure for the fixation of the toner onto the substrate. This means that the electro photographic technology will dry the substrate a little bit more than the liquid toner technology. For more detailed information about the printing process, see for example Handbook of Print Media (Kipphan, 2001).

The loss of print quality in comparison with traditional printing is one of the most frequently discussed topics when it comes to digital printing. We must not forget the importance of a satisfied runnability, however. Poor runnability will cause higher production costs, loss of time, few substrates to choose from and maybe problems in future finishing and functionality. Even if there is a possibility to achieve good print quality in a certain press, there is no way to get this result if the substrate is unable to pass trough the press in a smooth way. Those problems are common both for paper qualities and paperboards, but it may be more difficult to handle thicker and stiffer substrates like paperboards.

The discussion above makes it easier to understand how important it is to find out why some substrates cannot be printed in some digital presses and why some of them can. In addition to the previous it is also important to learn about defects included on the substrate while printing because such defects will affect a later finishing or function.

Materials and methods

In order to study the problems that can occur during paperboard printing in digital print units, several printing trials were preformed. The appearance between substrate and press were noted while printing. If a problem occurred, it was described as detailed as possible and if there seemed to be an obvious explanation this was also noted. This part of the study was very subjective. For every deviation during printing, an attempt was made to explain the problem with different measurements on the substrates. Following headings provides information about what kind of substrates, print units and measurements that were used. Also the preparation before the printing trials is described below.

Preparation

Because of later print quality measurements three different test files were created in QuarkXPress. The test files were created in different sizes according to what size the press could manage. With these files the press could always be tested with the largest possible format in every trail.

Print units and materials

In order to attain a broad study ten different substrates were used, of the following qualities: solid bleached board, solid unbleached board, sack paper and a paper quality. Neither folding box boards nor white lined chipboards were used in this study.

The eight different boards had different characteristics. Three of the qualities were solid unbleached board for liquid packaging and five were solid bleached board for graphical products. See the table of the substrates that were used below. All substrates that start with an L are board for liquid packaging, all substrates that start with a G are boards for graphical products, S is a sack paper and P is a paper quality.

One of the properties that differ between the substrates is the surface structure, because of various calendering and coatings. It is also very important to realize the fact that the liquid boards were not equilateral. Below it is possible to see some of the characteristics of the substrates that were used in the study (table 1).

Substrate	L1	L2	L3	G1	G2	G3	G4	G5	S	P
Grammage	192	180	120	250	220	220	210	240	80	130
Coating	matt	matt	-	gloss	matt	matt	matt	matt	-	silk

Table 1, shows the different substrates that were used in the printing trials.

The above-mentioned substrates were printed on five different print units. Four of the print units were based on dry toner electro photography, while the fifth were based on liquid toner technology. The table below shows the print units that were used in this study (table 2).

Print unit	Elpress A	Elpress B	Elpress C	Elpress D	Liqtoner
Max grammage	300	300	250	250	300
Feeding		Vacuum		Vacuum	Vacuum
Feeder	Web fed	Sheet fed	Web fed	Sheet fed	Sheet fed

Table 2, shows the different print units that were used during the printing trails.

Printing

The goals of printing trails were to achieve the best possible print result when it comes to runnability and print quality. This means that the results were placed in the hands of the different print managers. Samples from each substrate and press were picked both before and after printing for later measurements. The following table shows the substrates that were printed in each print unit.

Substrate/ Print unit	*P*	*S*	*G1*	*G2*	*G3*	*G4*	*G5*	*L1*	*L2*	*L3*
Elpress A	x	x	x	x	x	NO	x	x	NO	NO
Elpress B	x	x	x	x	x	NO	x	x	x	x
Elpress C	**x**	x	x	x	x	x	x	x	x	x
Elpress D	x	x	x	x	x	x	x	x	x	x
Liqpress	x	x	x	x	x	x	x	x	x	x

Table 3, shows which substrates that were printed in the different print units.

Subjective observance

While printing in the five different print units the runnability were subjectively observed. The observations were preformed by the author and if any problems occurred the print managers were consulted. The zones of possible problems were divided in three parts; feeding, transportation and out feeding. The behavior of each substrate was noted for each zone and a probable reason for the behavior was also noted by consulting the print manager.

The three parts were marked on a scale from one to five, were five stands for the best possible runnability. The list below shows the criteria to achieve a particular point. The difference between problem and disturbance in the list below is that a problem is something that prevents the press to continue by it self. Disturbance means some kind of none-normal sound or behavior that does not affect the substrates feeding, transportation or out feed through the press.

1. Very bad (press is unable to feed, transport or out feed)
2. Bad (feed, transport or out feed works but many problems occurs)
3. Approval (some problems during feed, transport or out feed)
4. Good (some disturbance occurs during feed, transport or out feed)
5. Excellent (no problems occur during feed, transport or out feed)

A comparison between the different substrates and the different print units are however largely a question of assumptions and beliefs of the printing group. Because of that it is difficult to establish which kind of substrate and print unit that is best. In order to understand and explain the problems measurements were also preformed.

Measurements

Before and after printing the temperature and the relative humidity were measured in the substrate with a hygroscope. The specific reason for this measurement was to investigate the loss of humidity in the substrate and also if the temperature was affected while printing. The temperature and humidity in the environment was also measured, just to check for large deviations. The recommended humidity during printing in liquid toner technology is set to 45-55% RH (Lamperth, 2001). In this case however, there was no possibility to control these values.

To find out if runnability properties depend on some kind of board characteristics or if the press created defects on the board while printing, the following measurements were preformed. After printing, both unprinted and printed samples were measured for thickness, bending resistance, surface roughness, tensile strength and tearing resistance. The table below shows the different measurements and the amount of measurement that were preformed.

The procedure for measuring thickness, bending resistance, tearing resistance and tensile strength can be studied in Pappersteknik (Fellers et al., 1996).

Measurement	*Thickness*	*Surface roughness*	*Bending resistance*	*Tearing resistance*	*Tensile strength*
Amount of measurements	6	6	4 x 2 x 2	2 x 2 x 2	2 x 2 x 2
Unit	µm	µm	mN	mN	k/N/m

Table 4. The table shows the different measurements (not humidity and temperature) that were preformed after printing. The first number (amount of measurements) is the amount of measure points, the second number stands for CD/MD and the third number stands for before and after printing.

Results

The results of the printing trials were very dissimilar between print units and substrates. In the following headings the most interesting results will be shown.

Subjective observations

Results show that the paper quality close to all the coated solid unbleached boards mostly achieves the best runnability. Some problems yet occurred in the feeding process when especially two sheet fed print units had difficulties to handle substrates with curl. One of the print units worked better if the front side in the feeding tray had a convex curl, while the other press worked better with a concave curl. Because of this it is really important that the substrate has a level plane. If it is impossible to achieve a plane level you have to know what kind of curl that works better. A wrong curl makes it very difficult to pick up the substrate. This result is reinforced with earlier results that show that especially print units based on liquid toner technology not accept curl (Modo Paper, 1999).

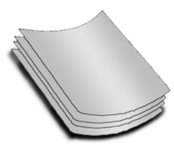

Figure 1. Concave curl

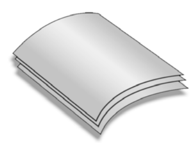

Figure 2. Convex curl

After printing the curl increased in almost all print units and substrates, but the largest curl was seen in substrates that lost a lot of humidity. This means that print units that dry the substrate produce more curl.

God runnability was a little bit harder to achieve on the sack paper next to the solid unbleached board. However, the problems with the solid unbleached boards were partly dependent on uneven edges and angles of the sheets, but mostly it depended on curl. The sack paper was mostly problematic in three ways. One of the problems was low opacity that caused stops during transportation in one of the print units. This occurred since the sensors could not feel that any substrate was passing by. The other problems probably occurred because of low stiffness and high porosity.

Problems with curl, low opacity and stiffness almost always occur in sheet fed print units. This means that sheet fed print units makes higher demands on the substrate.

The web fed print units has no problems during feeding or transportation, but the cutting units often cause problems. The web fed print unit that handles substrates with lower grammage has problems with thick and stiff substrates. Equilateral substrates with one very slippery side, like solid unbleached boards causes problems in the cutting unit in the web fed print unit that handles higher grammage. Sack paper is also problematic in the earlier mentioned cutting unit. The cause of the problems in the cutting units is however not clearly established. The following table shows the results of the subjective observance.

	ElpressA			Elpress B			ElpressC			ElpressD			Liqpress		
P	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
G1	5	5	5	5	5	5	5	5	1	5	4	4	5	5	5
G2	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5
G3	5	5	5	2	3	5	5	5	1	5	5	5	5	5	5
G4	N	N	N	N	N	N	5	5	4	5	5	5	5	5	5
G5	5	5	5	2	3	5	5	5	1	5	4	4	5	5	5
S	5	4	1	3	1	1	5	5	5	2	2	2	1	1	1
L1	5	4	1	2	3	5	5	5	1	2	4	4	2	3	5
L2	W	W	W	2	3	5	5	5	5	3	4	4	2	3	5
L3	W	W	W	2	3	5	5	5	5	2	4	4	2	3	5

Table 5. This table shows the runnability in the print units and substrates. The runnability is divided in three different parts; feeding, transportation and out feeding. The runnability is marked on a scale from one to five were five is the best result.

The following diagrams show the runnability in all five print units with four chosen substrates. Those substrates are chosen because of their special characteristics; one solid unbleached board, one solid bleached board, a paper and finally a sack paper. In the first diagram (1), each bar represents the mean value for the feeding, transportation and out feeding. It is possible to see that solid bleached board and paper passes smoother trough the press than sack paper and solid unbleached board. Overall the web fed presses seems to perform the best runnability and in one of those print units all substrates achieves quite good runnability when it comes to feeding and transportation.

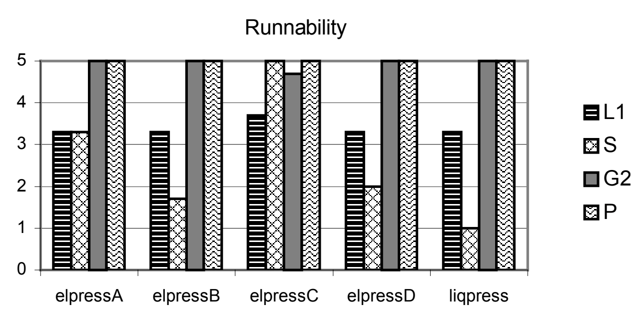

Diagram 1. This diagram shows the runnability in four substrates and five print units. Each bar is based on the mean value of feeding, transportation and out feeding.

When it comes to feeding also the web fed print units seems to get the by far best result. In sheet fed print units the problems seems to arise in the solid unbleached boards and the sack paper. During transportation the web fed print units also seems to perform the best result, especially the paper quality and the solid bleached board. But the solid unbleached board were also transported quite well. Following diagrams shows the result of feeding and transportation in three different substrates and five print units (diagram 2 and 3).

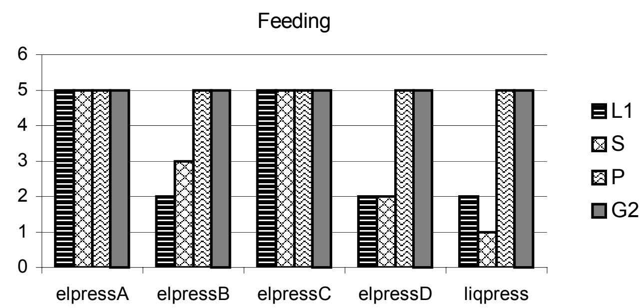

Diagram 2. This diagram shows the result of feeding in four substrates and five print units. The feeding is marked on a scale from one to five were five is the best possible result.

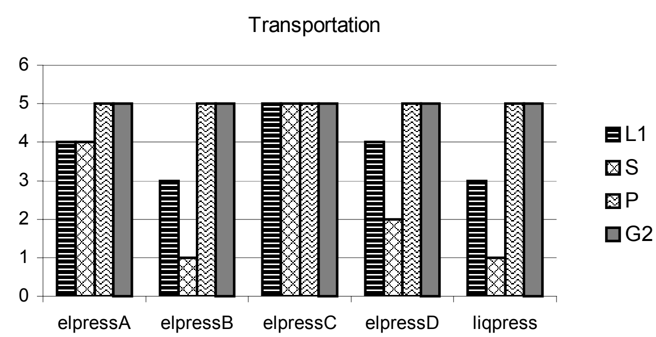

Diagram 3.This diagram shows the result of transportation in four substrates and five print units. The feeding is marked on a scale from one to five were five is the best possible result.

The out feeding achieved a better result in the sheet fed print units (elpress B and elpress C), except on the sack paper. As before, the solid bleached board and the paper quality achieved the best out feeding, but in all sheet fed print units the solid unbleached board seemed to achieve equal results as solid bleached board and paper.

Diagram 4. This diagram shows the result of out feeding in four substrates and five print units. The feeding is marked on a scale from one to five were five is the best possible result.

Changes in relative humidity

The relative humidity decreased during printing in all print units, but as can be seen in the diagram below (5) there is a big difference between the presses. The print unit that is based on the liquid toner technology does not affect the initial relative humidity that much and some substrates even increased their relative humidity during printing. The diagram (5) is however based on a mean value of six substrates (not ten) because every substrate could not be printed in every press. Included substrates were G1, G2, G3, G5, P and L1.

The paper quality, the sack paper and the solid unbleached board with low grammage and light coating lose more humidity then other substrates. This can signify that substrates with low grammage and less coating lose more humidity. Diagram 6 shows the difference between substrates with the lowest and the highest humidity loss.

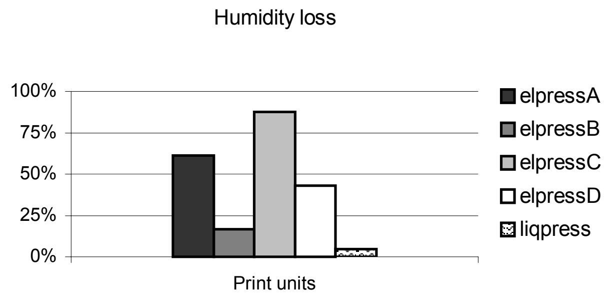

Diagram 5. Each bar shows the mean value of humidity loss (relative humidity) in six substrates printed on one print unit.

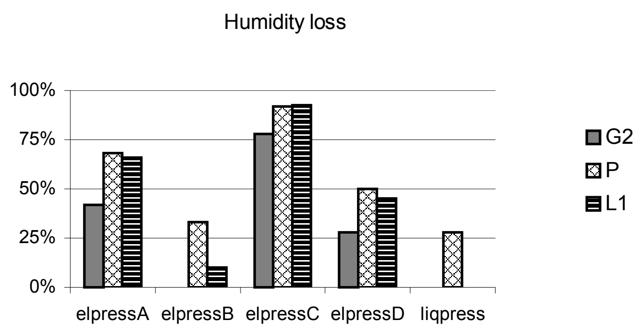

Diagram 6. Humidity loss (relative humidity) in three substrates and five print units.

Bending resistance

There are no big differences in bending resistance before and after printing. But it is possible to see a very slight decrease bending resistance in the fiber direction of the substrate. According to a source the bending resistance cannot decrease more than 15%, but in this study it sometimes does. However there is a possibility that different unprinted sheets of the same substrate have different bending resistance and then there is no possibility to prove that the print unit causes the defects. On the other hand the bending resistance almost seem to increase in the cross direction.

There are no visible differences between solid unbleached board and solid bleached board. The paper quality and the sack paper had too low bending resistance and because of that it was difficult to measure and to draw one's conclusions.

Even if there do not exist large differences between the print units or the substrates, it is possible to see that some sheet fed printers cause more decrease bending resistance in the substrates (fiber direction) than web fed print units do.

The following diagram (7) shows the changes in bending resistance in eight substrates and five print units.

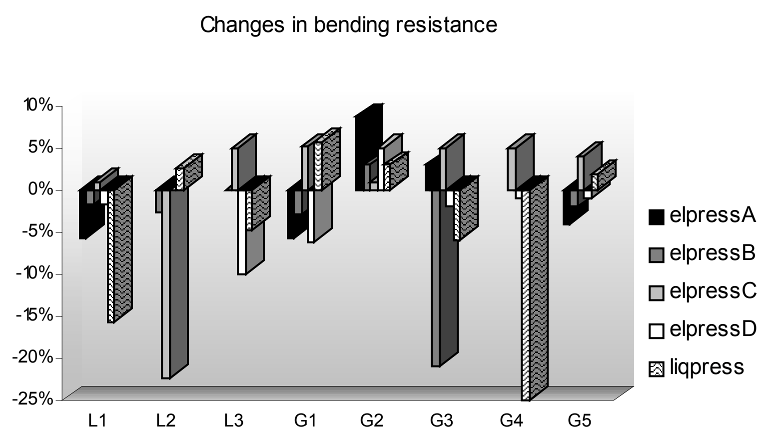

Diagram 7. The diagram shows changes in bending resistance before and after printing in five print units.

The initial bending resistance of unprinted substrates is difficult to relate to runnability. But according to one source (Lamperth, 2001) high stiffness improves the runnability. Another source reinforces this by telling that the only runnability problem depends on too low or to high stiffness (Piette, 2001). In this studies the results shows that most of the substrates with good runnability also have high bending resistance (diagram 10). This is however not true for the paper that has very low bending resistance. The sack paper that has the lowest bending resistance provides the worst runnability, however.

Relation between runnability and bending resistance

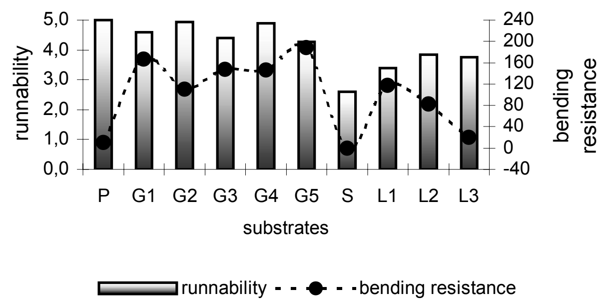

Diagram 10. The diagram shows how the initial bending resistance of the substrates affects the runnability.

Out feeding or transport does not seem to be affected if the substrate has a low or high bending resistance, except for the sack paper. But the feeding may be affected by substrate with low bending resistance. This is however not true for the paper quality that has no problems in runnability. A low bending resistance may cause more problems while feeding. See the following diagram. However this is only true for the sack paper and the solid unbleached board with the lowest grammage (L3).

Relation between feeding and bending resistance

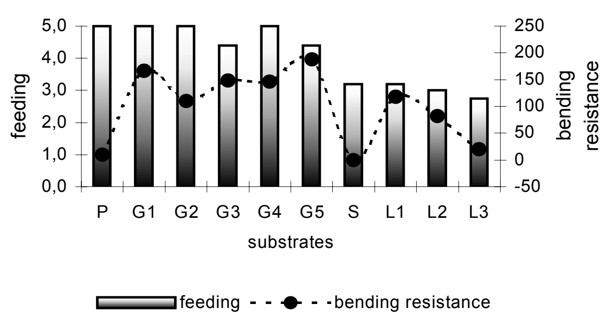

Diagram 11. The diagram shows if the initial bending resistance affects the feeding.

Tearing resistance and tensile strength

Measurements show that the printing process doesn't affect the tensile strength, but it is not examined if the original tensile strength affects the runnability. Instead the tearing resistance seems to be affected during the printing process.

There are no big differences in tearing resistance before and after printing, but it feels important to bring up the differences anyway. About two thirds of the total values show a decreasing tearing resistance. The differences in tearing resistance does not exceed minus 15% or plus 30%. Plus 30% seems to be a high value, but there are only six of fifty-three values that are higher then plus 5%.

Like bending resistance the tearing resistance seems to decrease more in sheet fed print units, especially elpress B and elpress D. It is almost impossible to find out which type of substrate that decreases more in tearing resistance. However, the measurements show that the paper quality and one of the solid unbleached boards with lower grammage decreased more. Like bending resistance the differences in tearing resistance appears to change more in the fiber direction.

Following diagram (12) shows the changes in tearing resistance (fiber direction) before and after printing.

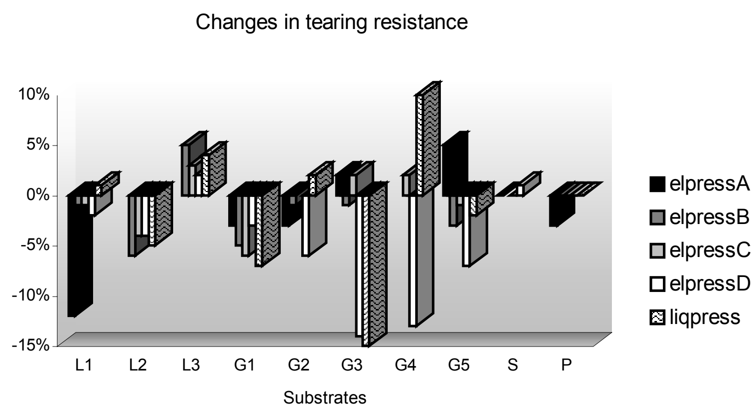

Diagram 12. The diagram shows the changes in tearing resistance (fiber direction) before and after printing.

Thickness and surface roughness

Thickness and surface roughness are two properties that may affect the runnability, but there are no measurement values that clearly show if a high thickness affects the runnability. But obvious you should not print a substrate in a print unit that expressly cannot handle a substrate with a certain thickness. However, a problem is that print manufacturers often set a limit in grammage and not thickness. A board can be much thicker then a paper but still have the same grammage.

Some problems can despite everything be connected to thickness. In elpress D some none-normal sound probably occurred due to a too high thickness. Also in one of the web fed print units (elpress C) problems occurred in the cutting unit probable due to a high thickness. Any further influences of thickness on the runnability are not yet established.

In the next page it is possible to see the results of the surface roughness but in the following table you can see the measurement values for both thickness and surface roughness.

Substrate	L1	L2	L3	G1	G2	G3	G4	G5	S	P
Thickness	260	219	152	278	228	268	264	291	171	113
Surface roughness	2,5	2,1	2,8	0,6	1,1	1,3	1,0	1,0	11,1	1,1

Table 6. The table shows the measured thickness and surface roughness of the substrates that were used in the study.

The surface roughness can more easily be connected to runnability. A substrate with higher surface roughness seems to have more problem to achieve a good runnability. Every substrate in this study that has higher surface roughness then 2,1 micrometer seems to achieve a worse runnability. This relation is, however, not established. Probably, problems in the cutting unit that arise on the solid unbleached board (web sheet print units) depend on equilateral sides, where one side is slippery and the other is rougher. Probably the slippery side of the board is skidding on the rollers in the cutting unit. In elpress D the substrate with the highest surface roughness seem to have problems especially while feeding, this may depend on both high surface roughness but even low stiffness.

The diagram (13) below shows the surface roughness in relation to the mean value of runnability for each substrate printed in five different presses.

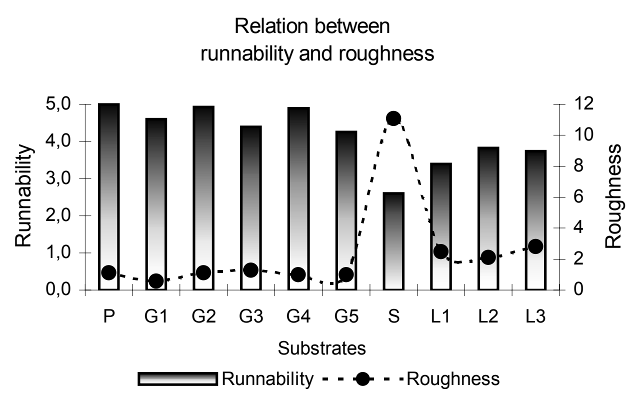

Diagram 13. The diagram shows the relation between roughness and runnability. Each bar is the mean value of one substrate printed in five print units.

Discussion

According to the measurements and the subjective observances it is possible to draw the conclusion that the paper quality next to solid bleach boards for graphical products gets the best possible runnability in digital print units. The sack paper achieves the worst runnability and this is due to the low stiffness, opacity and porosity.

Viewed on the hole the web fed print units give the best possible runnability, although, problems still occur on both web fed and sheet fed print units. The difference is that the web fed print units have problems in the cutting units, while sheet fed print units have problems during feeding. However, the problems in the cutting unit do not always depend on the substrates. Instead the problem could bee caused by the print unit.

Totally, the critical factors to achieve a satisfied runnability are stiffness, curl, thickness, porosity and eventually roughness. The stiffness must not be to low and this can be reinforced with earlier results on paper studies (Lamperth, 2001) (Modo Paper, 1999) (Piette, 2001). The paper quality however had the second lowest bending resistance in this study but achieved the best runnability and because of that, it is not proper to compare the stiffness between paper and boards.

Curl can normally not be accepted in sheet fed print units. If curl is impossible to avoid it is important to know if the print unit has a larger tolerance for concave or convex curl. Thickness must not be higher then the print unit can handle due to none-normal sounds and problems in the cutting unit. Roughness seems to affect the runnability negatively, but it is not established if this is a coincidence or not. Low porosity can create problems during vacuum feeding and this can be reinforced with earlier results (Modo Paper, 1999) (Lamperth, 2001).

Sheet fed print units seem to make a higher demand on the substrate than web fed print units. Problems in sheet fed print units occur because of curl, low stiffness and low porosity, but mostly curl. Web fed print units cause problems in the cutting unit. Why the cutting unit causes problems is not known. Probable explanations are that too slippery substrates skid on the rollers, machine problems and too low or too high stiffness.

There are no big differences between print units based on liquid toner and print units based on dry toner. The differences are largest between web fed and sheet fed print units.

During printing, the substrates are affected in three ways which reduces the possibility to achieve a good future function; humidity loss, loss in bending resistance and tearing resistance.

The humidity loss produces in the most cases curl, which can be a disaster for future function. The print unit based on liquid toner technology and one of the electro photographic print units however does not decrease the humidity in a large scale. The decreasing tearing resistance and bending resistance may not affect a later function, because of a slight decrease. But it may be interesting to know that there exist a slight reduce which may affect the life of a packaging product. Sheet fed print units seem to reduce the bending resistance more than web fed print units.

A recommendation for a future and excellent runnability in digital print units is a substrate with even edges and angles, plane level, approval thickness, not to low porosity, not to high or too low bending resistance and at last not too low opacity. If a substrate cannot fulfill this a web fed print unit for a better runnability is recommended. The problem is however a larger loss of humidity and sometimes problems in the cutting unit.

Today it seems like there still are some problems to overcome. The question is however if the print manufacturers or the producer of substrates will walk together and create better solutions, or if one of them has to compensate for the others problems.

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