紙表面につく傷の生成機構と耐傷性の要因（第１報）
—変形および破壊形態の観察と評価—

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Mechanisms on scratch generation on paper surface and factorial analysis of scratch resistance

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Abstract

Glossy coated paper is used as one of the highest quality paper products such as photographic-quality paper and high grade container boxes. However, once the surface is scratched, the resultant traces of the scratch are remarkable and detrimental to its glossy surface finish. Such scratches arise when the coated paper is subject to scratching actions in various contact situations such as a coating process, paper cutting process, and offset printing.

The objective of this research is to investigate the surface deformation properties during scratching. Two different kinds of commercial coated paper samples (inkjet-type and offset printing-type) were prepared for comparative study. The shape of scratches that arise on paper surfaces in scratch tests were determined by using a laser scanning microscope (LSM) to evaluate the deformation mechanisms.

The scratches were typically classified into two types; “plastic deformation” and “fracture”. The two types are different and independent, but often involved in one scratch. The cross-sectional deformation area and the onset load of crack generation were measured, and then the relationship between them was discussed. Consequently, the characteristics of scratches were influenced by the surface properties. Namely, low plastic deformation and high fracture toughness were suggested to be required for high scratch resistance.

Keywords: Scratch, Cast Coated Paper, Plastic Deformation, Fracture, Laser Scanning Microscope

1.　緒言

紙製品は最終ユーザーの手に渡るまで、多くの工程を経る（抄紙・塗工工程、仕上げ工程、印刷・加工工程等)。各工程において紙表面には摩擦や圧縮などの物理的な衝撃が加わる。このとき摩擦傷や凹み等が発生すると、特に平滑性が高く高光沢な紙の場合、欠陥部分そのものが微小であっても、その周囲の光沢性及び平滑性の高さにより傷の部分だけ反射光が散乱し、その結果、人の目による傷の認識が容易となる。傷発生の要因となる外力に対する抵抗性と定義される「耐傷性」は紙の重要な品質の１つであると考えられるが、傷の発生機構はほとんど解明されていない。

一般に傷の特徴を示す特性については、次の 3 つがあると考えられる [1)]。

1.　傷の大きさ
2.　傷の形状
3.　傷の目立ち易さ

傷の大きさは、筋状の溝の幅や深さ、長さなどの寸法であり、傷の形状は、溝の断面が長方形となるように鋭くえぐられているのか、あるいは円弧のように緩やかな凹みなのかといったことや、縁が盛り上がっているかというような寸法だけでは表現しにくい形態的な特徴を指し、傷の目立ちやすさは、周囲の無傷の部位の平滑度に対する相対的な傷の大きさのような概念を指す。

塗工層についた傷の特徴を評価する方法としては、肉眼による視感評価法が従来使用されてきた。これは官能評価であるため定量性・再現性には欠けているが、評価法としては一般的によく用いられている。しかし視感評価の場合「傷の目立ち易さ」の要因が大きく、傷の大きさや形状以外の要因である光沢のコントラストなどが大きく影響することから、実際の傷の形態的特徴について議論しにくい。

本報告では、「傷の大きさ・傷の形状」について着目し、レーザー顕微鏡（LSM）により実際の傷の形態観察を行った。次に、表面引掻き試験を行い、生成した傷の観察画像を解析して得られた傷の形態的特徴を同一の引掻き強度で比較することにより、各種塗工紙の耐傷性の評価を行った。最後に、その評価法に基づき、実際の印刷工程で生じた傷の形態的特徴について考察した。

2.　実験

2.1　試料

市販のインクジェット用キャスト光沢紙 2 種類（IJ シリーズ）及びオフセット印刷用キャスト光沢紙 2 種類（Pr シリーズ）を耐傷性評価用の試験試料として用いた。試料の詳細については表 1 にまとめた。

2.2　傷の形態観察

傷の観察及びその形状評価には、レーザー顕微鏡（VK-9720　Keyence 製、以下 LSM と呼ぶ）を使用した（倍率 3000 倍の設定、深度画像及び 3D 画像による観察）。後述の変形断面積の測定では、付属のデータ解析ソフトを用いた。ヒビ発生荷重の判断は、観察画像の目視により行った。

2.3　耐傷性評価

一定条件で引掻き動作を行う装置として、連続加重式引掻強度試験機（TRIBOGEAR TYPE:18L　新東科学製）を使用した。この試験機は、図 1 に示すように、針を使って一定条件で試料を走査して引掻き試験を行うことができる。試験荷重は、分銅を用いた定荷重試験だけでなく、針に与える荷重を連続的に変化させながら傷が発生し始める荷重を測定できる連続加重試験も行うことが可能である。今回の試験用の引掻き針は、先端径 30μm のサファイア針を使用した。

2.4　印刷試験機を使用した試験

サンプルを、一定条件において印刷機に通し、傷の評価を行った。印刷機は、枚葉式オフセット印刷機（三菱ダイヤ 6 色機、三菱重工業製）を使用した。印刷速度は 9000 枚/時間、また印刷パターンは、1 胴目及び 3～6 胴目を空通しニップ無し、2 胴目において非塗工面の単色画線印刷を実施した。印刷機に通すことにより発生した傷について、傷の大きさの計測及び形状の観察を行った。

3.　結果

3.1　傷の観察

はじめに、傷の評価を実施するために実際の傷を観察し、その形態の差異について比較を行った。図 2 に、傷の入ったキャスト光沢紙（インクジェット用、IJ-A）の LSM 写真を示す。図に示すように、傷のタイプは大きく 2 種類に分類できることが分かった。一つのタイプは、図 2(a)のような押し込まれた形態、もう一つのタイプは図 2(c)のような削り取られた形態を呈している。本報告では、以降それぞれを「塑性変形タイプ」と「破壊タイプ」という言葉で表すことにする。しかし実際の傷は、図 2(b) のように両方の要因が組み合わさっている場合が多い。過去の報告によると、塗工表面へのダメージが大きくなるにつれて、弾性変形→塑性変形→破壊の順に変化していくと言われている [2, 3]。

3.2　針引掻き試験による傷の評価

3.2.1　変形断面積

図 3 に、針引掻き試験において針に与える荷重を増加させた時の変形断面積の変化を示す。変形断面積とは、図 1 に示すように、引掻きにより生じた凹み部分の断面積である。図 3 は、荷重が増加するにつれて変形断面積も増加することを示す。この増加の傾向は直線的ではなく、2 次関数的な増加を示すが、ここでは議論しないことにする。オフセット印刷用キャスト光沢紙（Pr-A、B）はインクジェット用キャスト光沢紙（IJ-A、B）よりも変形断面積が大きいことがわかる。

この理由については、それぞれの試料の塗工層構造に起因していると考えられる。図 4 に、SEM による表面観察写真を示す。塗工層の表面を比較すると、Pr-A 及び B は空隙が多いことが確認できる。バインダーの硬さにも依存するが、一般的に空隙の多い方が、外力を加えられた場合に変形量が大きい。また、これらの塗工層に使用されている顔料であるカオリン粒子は扁平な形をしているため、引掻き傷のような外力により面配向し易い傾向があることが考えられる。これらの要因により傷が大きくなったと考えられる。これより、外力を加えられたときの変形断面積を小さくするためには、空隙を少なくして塗工層を密にすること及び面配向しにくい顔料を使用することが効果的であると推測する。

3.2.2　傷の観察

各荷重にて実施した針引掻き試験後の傷を、LSM で観察した写真を図 5 に示す。試料 IJ-A は、針荷重が小さい場合（20mN）には、図 5(a)に示すように塗工層表面は凹みのみが発生する。荷重が大きくなる（100mN）と、図 5(b)に示すように凹みが大きくなってくるが、同時にヒビも発生している。このヒビが発生し始める荷重を、塗工層の破壊が始まる点として着目した。Pr-A は、図 5(c)、(d)に示すように、IJ-A と比較すると破壊の発生しにくい塗工層であることがわかる。

同様に、それぞれの試料について、ヒビが発生する荷重について観察及び測定を行った。観察した画像から目視で判断し、ヒビ割れが認められる画像の荷重条件の中で最も低い荷重をヒビ発生荷重とした。各試料の比較を図 6 に示す。全体的な傾向として、IJ-A、B の方が、Pr-A、B と比較してヒビ発生荷重が低い傾向にある。つまり、試料 IJ はヒビ割れしやすい性質をもつ塗工層であると言える。理由として、IJ 用途はインクジェットインクを吸収する必要がある為に塗工層中のバインダー配合量を少なくする必要があり、そのために強度が低下してヒビ割れしやすい傾向を示すと考えられる。また、バインダー自身の物性（硬さ、伸び、脆さ）なども影響が大きいことも推測される。以上のことから、印刷適性を損なわない範囲で、塗工層表面を密にして変形しにくくすること、またバインダー配合を増やすことで割れにくくすることが対策として考えられる。

3.2.3　変形断面積とヒビ発生荷重との関係

材料は、一般にひずみと応力が比例する弾性変形が、ひずみの小さいごく初期に見られる。引掻き試験では針の先端部分で塗工層が圧縮されると考えられ、塗工層の場合もごく初期に圧縮弾性変形があるはずであるが、顔料/バインダー間の接着が部分的に破壊しやすいためすぐに塑性変形に変わり、応力を取り除くと永久ひずみが残る。これが一般的に塗工紙表面に生成する傷であると考えられる。塗工層によっては、変形しやすい、つまり簡単に塑性変形が生じやすい性質を示すものもあれば、塑性変形を示すのは低荷重領域だけで、すぐに大きな破壊を起こしてしまうものもある。このような性質は一般に脆性と呼ばれ、引掻きで生じるヒビ割れは、脆性破壊と考えられる。しかし、観察結果からも分かるようにヒビ割れは周期的に起こるため、ヒビ割れが発生した直後の隣の部位は変形が小さくなる。このときヒビとヒビの間は塑性変形が起きるため、部位によって脆性破壊と塑性変形が混在することになる。脆性を示さず破壊強度の大きい塗工層は、塑性変形が高荷重領域でも続くので、大きな変形を示すことになる。そこで 1 つには、脆性破壊（ヒビ割れ）が発生し始めるヒビ発生荷重を考え、もう 1 つには、塑

性変形のしやすさ、すなわち変形断面積の初期増加率（塑性変形領域での荷重増分に対する変形断面積の増分の割合）を考え、この 2 つを指標とする耐傷性の評価を検討した。

図 7 に、荷重増分 1mN 当りの初期変形断面積増加率（傾き）（$\mu m^2/mN$）とヒビ発生開始荷重の関係をまとめた。IJ-A と IJ-B で比較すると、IJ-A の方が、変形断面積が小さく、ヒビ発生開始荷重が高かった。このことから IJ-A の方が優れた耐傷性を持つと評価される。しかし IJ シリーズと Pr シリーズのような異なる製品用途のキャスト光沢紙を比較した場合、IJ シリーズは初期変形断面積増加率が小さいが、ヒビ開始荷重は Pr シリーズの方が大きいというように傷の特性が異なった。この場合、耐傷性の比較は難しく、表面が擦られる際の条件（速度、衝撃など）により、その優劣が変わってくると推測されるが、今後さらなる検討が必要である。

3.3　印刷工程で発生する傷の比較

IJ-A と Pr-A について、印刷機を使用した場合の傷の発生状況を比較した。結果は、表 2 に示すように、IJ-A の方が傷の本数が少なく、かつ傷の大きさ（傷の変形断面積）も小さい傾向を示した。また傷の大きさの傾向は、針引掻き試験の変形断面積の結果と一致することがわかった。

図 8 に、発生した傷写真の一例を示す。IJ-A は破壊されたような形状であり、Pr-A は周囲に断片がなく、凹んだだけのような形状であった。また全ての傷について観察を行ったが、傷形状の傾向は同様であった。これは針引掻き試験のヒビ発生荷重の結果と同じ傾向にある。このように、実際に発生する傷の大きさや形状の傾向は針引掻き試験による変形断面積とヒビ発生の開始荷重を測定することで推測が可能であると言える。これらのことから、耐傷性の優れた表面にするためには塑性変形が小さく、かつ破壊強度の大きな特性を持つ塗工層であることが必要であると考えられる。

4.　まとめ

市販のキャスト光沢紙を用いて、塗工層に発生する傷についてその形状の比較、考察を行った。LSM を用いた傷の観察より、傷を、塑性変形タイプと脆性破壊タイプに分類できることがわかった。針引掻き試験の結果を合わせて考えると、変形断面積が大きかったオフセット印刷用キャスト光沢紙試料は凹み傷が多い塑性変形タイプ、ヒビが入りやすかったインクジェット印刷用キャスト光沢紙試料は脆性破壊タイプの傷になり易い傾向が見られた。

光沢層の耐傷性を向上させるためには、塗工層表面を密にして変形しにくくすること、さらにバインダー配合量を増やすことで割れにくくすることの両方が必要であることを結果から示唆される。しかし、水性インクの高吸収速度が求められるインクジェット塗工層をこのような材料配合で製造することは困難であるが、1 つの欠陥から連鎖的に破壊が進行する脆性破壊が起こらないようにバインダーに柔軟性を付与したり、バインダーを局在化して強度が高い部位を分散させて配置したりするような構造的な改質により、耐傷性を向上させることは可能かもしれない。

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1. Introduction

Paper products are manufactured sequentially through various production processes like papermaking, coating, finishing, printing and converting until delivery to customers. In every process, its surface encounters mechanical impact like abrasion and compression. When even small scratches or dents arise on smooth and glossy surfaces, light reflected from the damaged surface is scattered detrimentally and they are easily recognized by human eyes because of the contrasting reflection. Therefore, scratch resistance, which is defined as resistance to scratching actions, is regarded as one of the important paper qualities. However, few studies have been done on the mechanisms of scratch generation.

In general, scratch issues can be characterized from following three properties[1)].

1. Dimension of a scratch
2. Shape of a scratch
3. Ease of recognition by eyes as a scratch

The dimension of a scratch is represented by parameters like width, depth, and length of the streak. The shape of a scratch is geometrical, and is classified under the shape of cross section of the streak, for example, a rectangular or concave with or without piled-up broken pieces on the edges. The ease of recognition is a relative appearance to the surrounding undamaged area in terms of smoothness.

As a method of evaluating characteristics of scratches on coated layer, visual inspection has been used. Though it is not quantitative and lacks reproducibility, it is still in common use. Evaluation by visual inspection is affected by factors relating to "ease of recognition", and the contrast in gloss which is a factor other than dimension and shape of the scratch is very influential to it. Therefore, it is not easy to discuss geometrical characteristics of scratch in general.

We paid attention to the dimension and shape of scratches caused in a regular handling operation and observed them with laser scanning microscope (LSM). On the other hand, we made scratches on surfaces of coated paper in surface scratch tests, analyzed LSM images of them, and then compared them at the same level of standardized scratching intensity. The results gave information on the scratch resistance of coated paper, and helped establish the evaluation method. Lastly, scratches caused in a commercial printing operation were examined on the geometrical characteristics, using our original evaluation method.

2. Experiment

2.1 Samples

Two each kinds of cast coated paper for ink jet (IJ series) and for offset printing (Pr series), all of which were available commercially, were used for scratch resistance evaluation. Details of the cast coated paper are listed in Table 1.

2.2 Observation of scratch

Laser scanning microscope (VK-9720, Keyence Corporation), abbreviated as LSM hereafter, was used for observation and evaluation of scratches. Observation was done at a magnification of 3000 as topographic images as well as 3D images. In the measurement of cross-sectional deformation area which will be discussed later, the software supplied with the equipment was used for the data analysis. Critical loads causing cracks were judged by visual inspection.

2.3 Evaluation of scratch resistance

Scratch tester (TRIBOGEAR TYPE: 18L by SHINTO Scientific Co. Ltd.) which can increase the load on a sheet surface continuously and repeat tests at the same condition was used As depicted in Fig.1, scratches were made with a needle run in contact with a sheet surface. The mode of load application to the needle can be controlled to be either constant or incremental. The critical load causing a scratch can be determined from the load on the needle in the incremental mode. The needle used in the test was made of sapphire and the diameter of the tip was 30μm.

2.4 Scratch test by printing press

Samples were printed through a printing press under the constant condition and resultant scratches were evaluated. The printing press was a sheet offset printing press (Mitsubishi DAIYA 6 color-printing press by Mitsubishi Heavy Industries, Ltd.). The printing speed was 9000 sheets per hour. Cylinders No.1 and No.3 to No.6 cylinders were non-operated with no nip pressure. Only at cylinder No.2, printing was done with a line pattern of a single color on uncoated surfaces. Scratches caused by passing through the printing press were evaluated in terms of the dimension and shape.

3. Results

3.1 Observation of scratches

Firstly, scratches found on surfaces of commercially printed sheets were observed and they were compared to each other in terms of the shape. A scratched surface of cast coated paper (offset printing grade, Pr-A) are shown in Fig. 2. Scratches like these were frequently observed, and we found that such scratches were classified into two types; plain dents as shown in Fig. 2(a) and dents with fracture as shown in Fig. 2(c). We defined them “plastic deformation type” and “fracture type”, respectively. However, in most cases, scratches are generated from a complex combination of the two types. It is generally known that coat surface damages proceed from elastic deformation, plastic deformation, and finally to fracture[2, 3].

3.2 Evaluation of scratches by needle scratch tester

3.2.1 Cross-sectional deformation area

The cross-sectional deformation area (abbreviated as CSDA hereafter) of the scratch generated with increased load on the needle of the tester was measured. The result is shown in Fig. 3. As the load increased, the CSDA also increased. Though the change is not linear and looks like a curve of second order, we will not discuss it in this paper. It was clear that the cast coated paper for offset printing (Pr-A and B) had the larger CSDA than the cast coated paper for ink jet printing (IJ-A and B).

The difference in CSDA was supposed to be due to the coated layer structures. Coat layer surfaces of the two kinds of coated paper are shown in Fig. 4. The SEM photos show that Pr-A and B had more void volume. In general, coatings with more void volumes are more easily and more largely deformed by external force, though the hardness of binder may be influential to some extent. Kaolin particles in such coated paper are platy and tended to be aligned in a plane easily by scratching force. This property, in addition, was supposed to cause scratches to be larger. As an effective remedy to reduce CSDA caused by external force, coatings should be dense with less void and the pigment particles that tend to be less aligned should be chosen.

3.2.2 Observation of scratches

The coated paper samples were tested with the needle scratch tester at various loads, and resultant scratches were observed with LSM. Topographic images are shown in Fig. 5. For sample IJ-A, only dents arose on its coat surface at a load of 20mN as shown in Fig. 5(a). When the load reached 100 mN, the dent became larger and cracks were observed as shown in Fig. 5(b). We paid attention to the load which began to cause cracks as a starting point of fracture of the coat layer. Pr-A had a coat layer which is less likely to be damaged than IJ-A as suggested by Fig. 5(c) and Fig. 5(d).

Every sample was tested at a wide range of load both below and above the level at which cracks began to arise on the surface and every crack was observed with LSM. The LSM images as shown by Fig. 6 were checked visually to obtain the minimum load generating a crack and it was defined as the onset load of fracture. IJ-A and B produced cracks at loads less than those for Pr-A and B. In other words, the IJ samples had coat layers which were more easily damaged than those for the Pr samples. Because ink jet paper has to absorb ink jet inks and the binder contents of coat layers should be reduced to low levels for high ink jet quality. The strengths of IJ-A and IJ-B were possibly low and they tended to be cracked easily. Binder properties such as hardness, stretch, and fragility might be speculated also to influence the behavior. In short, the action to take for improvement is to design coat layers with high densities as long as printing quality is maintained and to increase the binder content to reinforce the coat layer to prevent breakage.

3.2.3 Relationship between CSDA and onset load of fracture

Elastic deformation, with strain proportional to stress, is generally observed in the low strain region. In the needle scratch test, coat layers were compressed by the needle tip and deformed elastically in the beginning of the test. With increased stress, however, adhesion between pigment and binder became easily broken and it transferred to plastic deformation. After the load was removed, the deformation resided as a permanent set. We believe that this is a type typical of scratches generating on coat surfaces. Some coat layers deform easily and transfer to plastic deformation in early stages of deformation, others deform in the plastic mode only in the low load region, but become fractured immediately afterwards. The latter pattern is called brittle fracture and cracks caused by scratching force are thought to be the case.

Cracks, however, occurred periodically as implied by the images, and the deformation immediately after the crack generation became smaller. From this observation, the deformation between cracks was considered to be plastic deformation. Therefore, in some areas, there coexisted brittle fracture and plastic deformation.

Coat layers which had high fracture resistances to brittle fracture kept plastic deformation even in the high load region and showed a large amount of deformation. Therefore, we proposed following two parameters to evaluate scratch resistance. One was the onset load of fracture at which brittle fracture starts. The other was the ease of plastic deformation represented by the initial gradient of CSDA (the ratio of CSDA increase to the load increase in the range of plastic deformation).

Fig. 7 depicts the relationship between the rate of deformation advancement ($\mu m^2/mN$), that is, the ease of plastic deformation at a load of 1 mN and the onset load of fracture. When IJ-A was compared to IJ-B, IJ-A had the smaller CSDA and higher onset load of fracture. The IJ series and Pr series designed for different uses, respectively, were compared to each other although they were both cast coated papers. The IJ series showed the lower rate of deformation advancement. On the other hand, the Pr series showed the higher onset load of fracture. As they had pros and cons of deformation properties in the counter directions, it was difficult to judge which series had the better scratch resistance. It would be dependent on the condition (velocity and impact) of a scratching force impacting paper surfaces and further study is needed for the verification.

3.3 Scratches during printing

IJ-A and Pr-A were passed through the printing press and their scratches were compared to each other. The results are summarized in Table 2. IJ-A had the fewer scratches, which are commonly smaller in the dimension. This observed trend about the dimension of the scratches corresponded to CSDA values in the needle scratch test. Fig. 8 shows example photos of scratches. The scratch of IJ-A looks fractured. That of Pr-A looks like a long dent with piled-up pieces on the edges. We observed all other scratches and confirmed that the trend of difference between IJ-A and Pr-A. This finding corresponded to the scratch resistance observed generally at the onset load of fracture in the needle scratch test. It was concluded that scratches caused on paper surfaces during regular operations could be predicted by measuring CSDA and the onset load of fracture in the needle scratch test. It would be indispensable to provide coat layers with a property of low plastic deformation and high resistance to fracture strength, in order to make the surface resistant to scratching.

4. Conclusion

Cast coated paper commercially available was used to characterize scratch formation on their surfaces in terms of the dimension and shape. From a viewpoint of scratch resistance, coat layer surfaces were classified into two types; plastic deformation type and brittle fracture type by the observation of LSM. In consideration of the result of the needle scratch test in addition, scratches on cast coated paper for offset printing are of the plastic deformation type, that is, mainly dents with large CSDA values; those for ink jet are of the brittle fracture type, that is, dents with cracks and pile-up edges resulting from fracture.

To increase scratch resistance, it was suggested that surfaces of a coat layer should be dense enough for deformation resistance and stiff enough for cracking resistance by decreased binder content. However, it is difficult to modify coat layers for ink jet satisfactorily to requirements to absorb an aqueous ink jet ink quickly for print quality. However, there would be some probable solutions. One is to use flexible binder which will help decrease brittle fracture which begins to proceed with one small crack. Another is to modify binder distribution so that binder becomes localized at a micro scale level and high strength domains are distributed in a sheet adequately to prevent sequential facture generation.

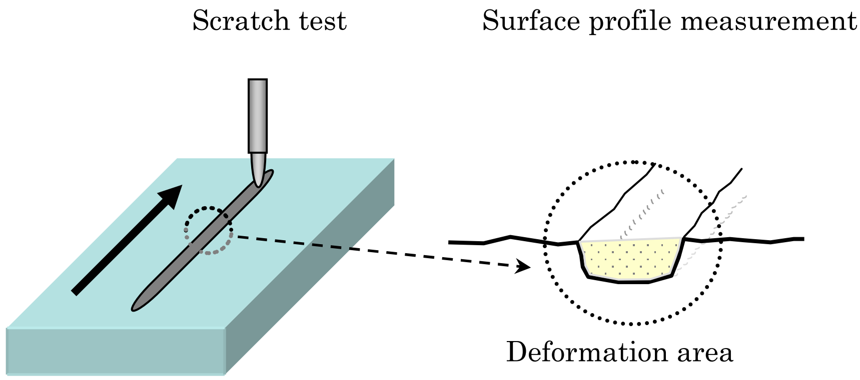
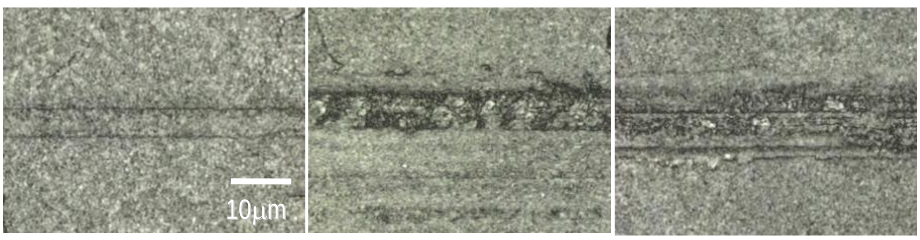


Fig. 1 Cross-sectional deformation area of a scratch

Table 1 Commercial cast-coated paper samples

Sample	IJ-A	IJ-B	Pr-A	Pr-B
Purpose	Inkjet Printing	Inkjet Printing	Offset Printing	Offset Printing
Pigment	Silica	Silica	Kaolin, $CaCO_3$	Kaolin, $CaCO_3$
Main Binder	PVA*	PVA*	SB-latex*	SB-latex*
Coating thickness (μm)	12	24	20	20
75 º Gloss(%)	86	66	92	86
Bekk smoothness (s)	60	80	230	70

*PVA and SB-latex denote poly-vinyl alcohol and Styrene-butadiene latex, respectively.



(a) Plastic deformation type (b) Mixed type (c) Fracture type

Fig. 2 LSM images of 3 different types of scratches on coating layers of cast-coated inkjet paper

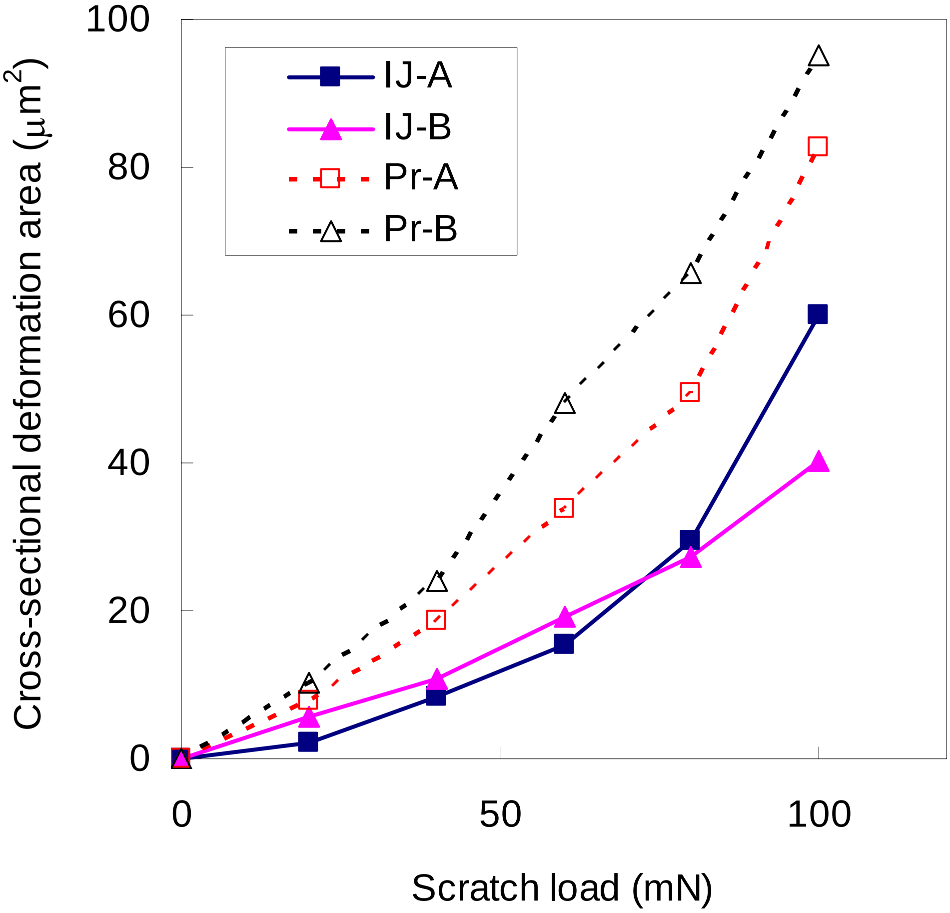
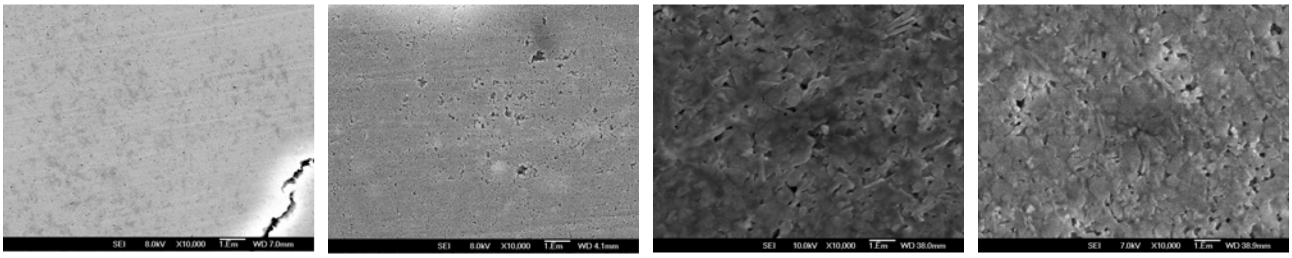
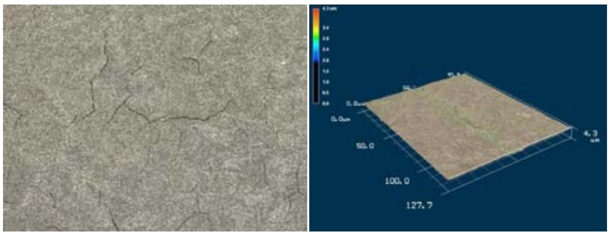


Fig. 3 Correlation between deformation and load

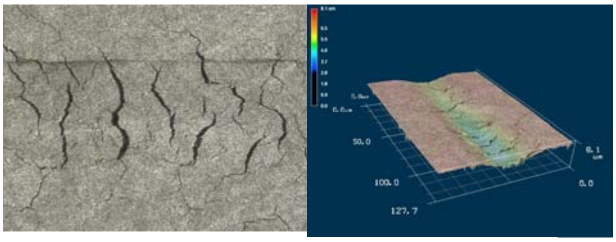


IJ-A IJ-B Pr-A Pr-B

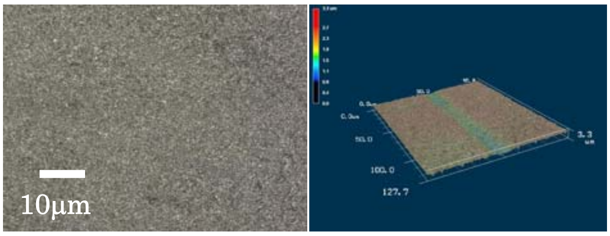
Fig. 4 SEM image of the 4 samples



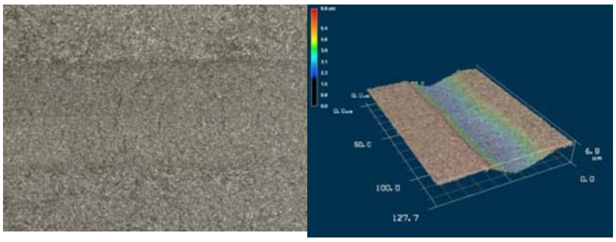
(a) IJ-A, 20mN scratch load



(b) IJ-A, 100mN scratch load



(c) Pr-A, 20mN scratch load



(d) Pr-A, 100mN scratch load

Fig. 5 LSM images of scratches generated in scratch tests

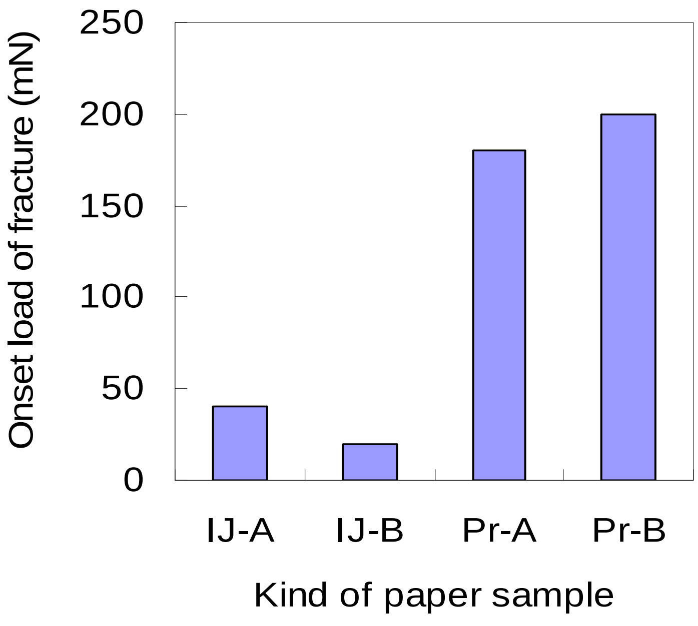


Fig. 6 Comparison in onset load of coating layer fracture

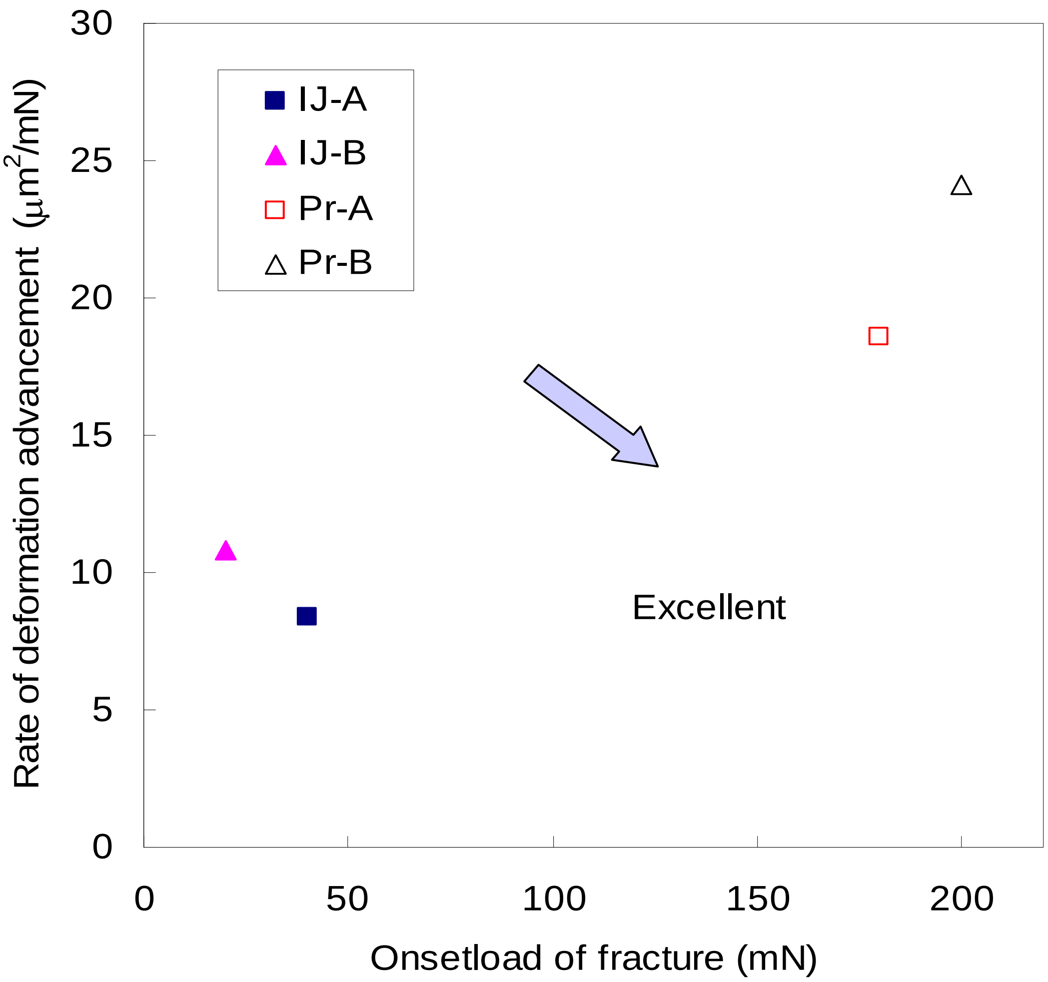


Fig.7 Correlation between deformation rate and fracture onset load

Table 2 Results of printing test

Sample	IJ-A	Pr-A
Frequency of scratch occurrences	4 lines/sheet	9 lines/sheet
Cross-sectional deformation area (Ave.)	3μm²	10μm²

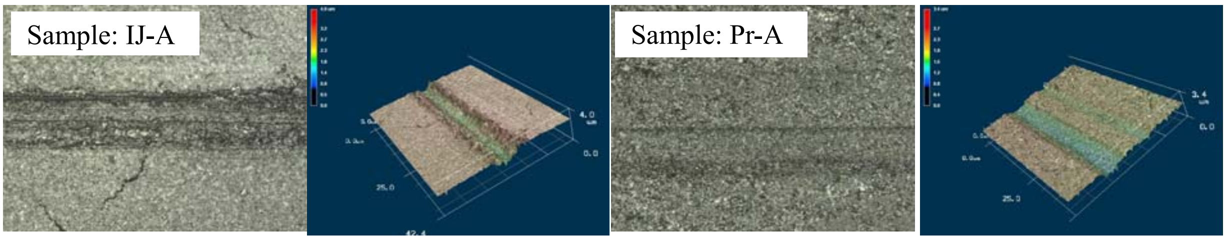


Fig. 8 Topographic (left) and 3-dimensional (right) LSM images of scratched surface after offset printing