Future Evolution of Pressure Sensitive Adhesive Tapes

Director, Adhesive Tape R&D Center
SANO Kenji

1. Introduction

Because of its characteristic ability to adhere instantaneously to any substrate and its advantage of allowing processing into any desired shape, adhesive tape is an extremely convenient material and is used widely in industry. It is therefore not surprising that, until 1991, Japanese adhesive tape output grew steadily in line with the country's economic growth. Development activity in the adhesive tape industry during this period consisted of projects to open new applications and of research to enhance the performance of adhesive tape so as to expand its scope of use. Replacing cloth impregnated with pitch or tar as electric insulation material, or, in the form double-sided adhesive tape, taking over from pins, screws and other metal fastenings were among the ways in which adhesive tape applications grew by supplanting conventional methods of processing[1]. This process was accelerated by enhancement of adhesive tape performance thanks to the development of new materials by the rapidly advancing science of petrochemistry. However, as shown in **Fig. 1**, since the bursting of Japan's economic bubble in 1992, adhesive tape production has flattened under the influence of economic recession.

In order to escape from stagnation and take off on a renewed growth curve, the product must once again establish new applications and expand its range of use. Luckily for the industry, the electronic communications sector centered on computers, mobile telephones and similar devices has recently enjoyed phenomenal growth, sparking demand for high-level functions and performance in the adhesive tape which is widely used as a processing or supporting material. With developments in the field moving at a furious pace, multifarious requirements have arisen; this presents an opportunity for the adhesive tape industry to resume growth. To exploit this opportunity it is essential to respond swiftly to user requirements, which in turn requires rapid progress in the development of sophisticated functions in adhesive tape.

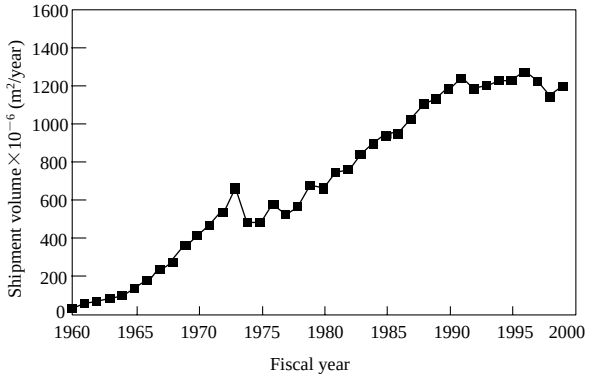

Fig. 1 Adhesive tape shipment in Japan

At the same time, the recent growth in concern for the environment not only offers new business opportunities; it also carries the risk of business failure for those who ignore it and is therefore an issue which the adhesive tape industry must face. The present paper thus concentrates on the twin aspects of developing sophisticated functions and tackling environmental issues in its appraisal of the future development of the industry.

2. Present Conditions for the Adhesive Tape Industry

The movements likely to impact on the adhesive tape industry in the near future are product polarization and increasing awareness of environmental issues. Polarization here refers to a split between increasingly low-priced articles on one hand and, on the other, articles with high degrees of added value and specialization in response to increasingly sophisticated requirements. The latter involves three trends: demand for new functions which conventional tape is unable to satisfy, demand for enhancement of existing functions, and demand for multifunctionality, i.e. high-level performance of the multiple functions required for various specific applications. The environmental

aspect can be divided into issues relating to adhesive tape production and issues relating to its use and disposal.

2.1 Production Technology for Cost Reduction

As cost competition is expected to intensify constantly in articles designed for existing applications and in those of low added value, low-cost production is a vital issue. Low-cost material procurement and production technology will be vital in this scenario. Low-cost material suppliers will expand and material procurement will become increasingly borderless. Regarding production, hitherto mass production based on large scale and high speed has been a major means of achieving low cost; in future manufacturers will be required to go beyond this to realize improved production yield, non-waste-generating production methods, and ways of allowing recycling or reuse of excess materials and energy. It is likely that there will be a move from separate to integrated execution of sequential tasks, such as preparation of the adhesive tape base, adhesive coating, and cutting.

2.2 Prospects for Development of Sophisticated Functions

Adhesive tape has expanded its range of applications on the strength of its ready adhesive characteristics and through addition of functions such as transparency, optical functionality, heat resistance, heat conductivity, insulation, soundproofing, vibration resistance, peelability, and flame resistance[2), 3), 4)]. This development is likely to continue with ever more sophisticated functions being required. For instance in the high-growth electronic and information technology sector, developments are moving at an extremely fast pace and sophisticated capabilities are required. Here, it is not enough for articles to offer a standard level of capability, as it is with general commercial articles; instead they need to offer distinctive capabilities and functions. While the move toward light weight and compact dimensions continues in electronic and information technology devices, there has been a rapid move toward larger dimensions in the field of display panels and screens.

2.2.1 Adapting to Increasing Lightweight and Compactness

It is generally said that the more adhesive tape is used, the greater the effect in terms of weight reduction. This is because a variety of parts can be fixed in place with a very thin layer of tape. When using tape to act on a restricted surface area, it is important to ensure adequate adhesive force by maintaining a parallel interface between the substrate surface and the tape surface; enhanced parts precision and elimination of mold warpage are therefore important goals. As tape with a cushioning component acts to maintain parallel interface, nonwoven cloth is often used as the base material for double-sided adhesive tape.

If precision deteriorates during adhesive tape pre-processing, burrs and other flaws may appear which reduce the adhesive surface area leading to insufficient adhesive force. Further, if the adhesive sticks to the cutting blade during processing, more frequent cleaning operations will be required. If the trend continues which favors processing into ever smaller shapes, tape design will need to evolve accordingly. In general, the thicker the tape the better its cushioning features, but the lower its workability. To design a tape that combines cushioning ability with workability, it will be important to make adjustments not only to the adhesive material and the base material but to the whole structure including the peel-off release liner.

2.2.2 Adapting to Display Screens

The world of display screens and panels is moving rapidly toward large-format models, and demand is growing for screen-surface functions such as static prevention, brightness control, glare prevention and shielding ability. This can be achieved either by treating the screen surface itself or by covering it with a functional film; with the advent of larger screens, the latter method is favored. In this case, the adhesive tape used needs to have the same optical characteristics as the optical film. Because optical adhesive tape requires transparency and durability, an acrylic material is generally used. Acrylic polymers basically have high transparency, but become opaque through the use of additives. The focus of material design is therefore how to produce good transparency and durability in the materials used in polymerization, for instance the initiator and cross-linking agents and the tackifier. In terms of production technology, impurity control of the same level of stringency as for optical film manufacture is required through creation of bioclean conditions.

2.3 Combination of Opposing Functions

Adhesive tape is rarely required simply to adhere; it nearly always has to provide a number of functions. In an increasing number of cases two or more of these functions stand in a relation requiring trade-off.

2.3.1 Combining Adhesive Power with Easy Removal

In the processing of electronic parts, for instance, it is often the case that firm adhesion is required during processing, but easy tape peelability afterwards. To satisfy both requirements, the tape is subjected to a form of energy other than mechanical energy to render removal easier.

1) Use of Heat Energy

Nitto Denko has developed a series of products (brand-names REVALPHA and REVACLEAN) which manipulate heat energy so as to alternately adhere firmly or peel off easily as required. The adhesive material of these products contains a foaming agent in the form of microcapsules which is activated when a certain temperature is reached. The foaming action converts the heat energy into the mechanical energy necessary for peeling, and allows the tape to be removed easily[5]. Naturally, the physical properties of the adhesive agent must be adjusted with care to allow effective energy conversion.

2) Use of Ultra-Violet Energy

ELEP HOLDER is the name of a product which manipulates ultraviolet rays to achieve release when adhesion is no longer required. Ultraviolet irradiation produces a chemical reaction in the components of the adhesive agent which causes them to harden and shrink. In this case, light energy is converted into the mechanical energy for adhesive release. The focus of technical development is how to concentrate the hardening and shrinking reaction at the adhesive interface so that a smaller amount of contraction will still produce adhesive release[6].

2.3.2 Combination of Adhesive Performance with Non-contaminating Properties

Normally, adhesive substances have a viscoelastic design to allow suppleness. In order to achieve this property, an additive of relatively low molecular weight is commonly used. Even acrylic adhesives, which provide sufficient adhesive strength with a polymer-only (i.e. tackifier-free) system, contain a sol component which does not contribute to cross-linking. Since cross-linking agents react more readily with substances of high molecular weight, the sol component which does not react with the cross-linking agent is thought to be of low molecular weight and low cohesive force. This substance of low-molecular weight and low cohesive force is one of the factors contributing to the adhesive property, but it produces contamination when the tape is removed by transferring to the substrate.

In general use this contaminant does not present a problem, but in the case of applications where external appearance is important or where adhesive removal is followed by coating, circuit formation, wirebonding or other such processes, minute quantities of contaminant can interfere with coating or prevent sufficient bonding strength being achieved. One way of preventing this kind of contamination is to reduce the amount of substances of low cohesive strength and reduce the compatibility of the adhesive agent and the substrate. One example of a product developed using this approach is the automobile paint protection film RAPGARD[7), 8)].

In double-sided adhesive tape, peel-off release liner is used to protect the adhesive surface. The release liner consists of paper or film coated with the peeling agent silicone. Although only a minute amount of silicone is used, it nevertheless gets transferred to the adhesive surface, and can in some cases have a damaging effect on electronic components. Where minute amounts of contaminant cause problems, the best solution would of course be to stop using the offending substance. However, it is difficult to find a replacement with the same excellent peeling qualities as silicone. In such cases it is necessary to examine not only the peeling agent but also to look for solutions in the adhesive itself. In recent years, a technology combining a condensation-polymer-based adhesive with polyolefin film has allowed the use of silicone to be dispensed with while nevertheless retaining equal peeling characteristics.

2.4 The Environment – an Unavoidable Issue

2.4.1 Environmental Issues During Adhesive Tape Manufacture

Adhesive tape is manufactured by coating a supporting base material with a liquid adhesive agent. There are various ways of liquefying the adhesive, but, because it allows high performance and can be used with a wide range of product types, widespread use is made of solvent-based adhesive, in which an organic solvent is used as the medium to dissolve the main polymer of the adhesive agent, the tackifier and the cross-linking agent. At Nitto Denko, the manufacturing process for solvent-based adhesives is closely controlled with a solvent recovery device and an incineration device used in the coating process. However, environmental installations require maintenance costs, and instead Nitto Denko is pressing ahead with conversion to production methods with low environmental burden. As techniques which reduce solvent use, the following have been applied in practice:

1) High-solid adhesive: including a high concentration of non-volatile material in solvent-based adhesive reduces the amount of solvent used per unit or production.
2) Emulsion-based adhesive: instead of dissolving in organic solvent, the adhesive agent is suspended as an emulsion in water. Water is thus used as the medium.
3) Hot-melt adhesive: adhesive coating is carried out by melting at high temperature.
4) Solid adhesive: solid adhesive softened at high temperature is coated using calender processing.
5) Ultraviolet polymerized adhesive: the adhesive raw material is applied to sheets and polymerized, allowing adhesive tape to be made without use of solvent.

The advantage of solvent-based adhesive is that it allows the use of almost all polymer bases including rubber and acrylic materials as the adhesive base, and allows an extremely rich variety of adhesive products to be created through use of various additives. **Table 1** gives a comparison with non-solvent methods of manufacturing. It is difficult to find a single method which can stand in for all the solvent-based processes; rather it is a question of perfecting a number of complementary technologies which between them can cover as much ground as possible. The importance of an environment-friendly method of production is growing constantly, and efforts will need to continue to reduce solvent use.

2.4.2 Environmental Issues During Adhesive Tape Product Use and Disposal

With the full enforcement from April 1, 2001, of a law on the recycling of electrical goods, industrial waste will become a focus of environmental concern. The law in question obliges manufacturers to collect used airconditioners, television sets, and washing machines and recycle them according to set criteria.

By bonding two objects together, adhesive tape allows the objects to fulfill new functions. When PVC-based vinyl tape is wound around copper wire, the PVC-film adhering to the copper surface produces an insulating effect and the result is surface-insulated copper wire. Double-sided adhesive tape is also used to bond substances together. Because of the nature of these adhesive tapes, the object bonded to the substrate is almost always one of a different substance. However, it is difficult to recycle parts with foreign substances adhering to them. Environmental considerations therefore demand that adhesive be made so that it can be removed easily when the appliance has reached the end of its useful life. Naturally, while the product is still in use, the adhesive function must remain reliable. One product developed in response to these requirements is the double-sided adhesive tape No. 5000 NS, which provides firm adhesion while the appliance is in use but can be removed neatly even after long periods of time.

In the future, there will be increased demand for adhesive tape whose design takes into account recycling and reuse of components. Meanwhile, since adhesive tape itself also even-

Table 1 Advantages and disadvantages of various production methods

Method	Advantages	Disadvantages
High-solid production	● Possible with existing coating facilities ● Performance close to that of solvent-based adhesive	● Not completely solvent-free ● High solid concentration leads to deterioration of performance
Emulsion production	● Environment-friendly water-based solvent ● Can be used with wide range of monomers ● Various functions available through use of additives ● Thin coating possible	● Poor moisture resistance ● Causes roughness of coated surface more easily than solvent-based method ● Thick coating difficult to achieve
Hot-melt production	● Compact production facilities ● High-speed manufacturing process ● Thicker coating possible ● Completely solvent-free	● Poor heat resistance ● Occasionally produces poor weather resistance ● Unsuited to thin coating
Calender production	● Thicker coating possible ● Completely solvent-free ● Coating of highly viscous materials possible	● Unsuited to thin coating ● Poor heat resistance
UV polymerized production	● Thicker coating possible ● Gives products with high heat resistance and high adhesive strength ● Solvent-free	● Unsuited to thin coating ● Use only with limited range of tackifiers
Solvent-based production	● Can be used with wide range of polymers ● Various additional functions available through use of additives ● Thin coating possible ● Can be used to make a wide range of adhesive products	● Fire hazard ● Workers exposed to solvent fumes ● Solvent disposal facilities required

tually ends up as industrial waste, it is important to consider the final disposal aspect when choosing the adhesive tape materials. Polyvinyl chloride, for instance, is a plastic material with many advantages including suppleness, weather- and flame-resistance and workability, but is said to release dioxin under certain circumstances when burnt, so that the trend now is to non-PVC materials. Polyolefin materials are used in many cases as replacement, but a new material with improved characteristics is awaited.

3. Future Development of Adhesive Technology

Towards continued progress in cost reduction, in addition of sophisticated functions, in reconciliation of opposing requirements, and in environmental adaptation, efforts are ongoing in the development of design technology, new materials, manufacturing technology, evaluation technology, and other areas. However, if adhesive technology is to advance in the future, new approaches are essential. One such new approach is the trend toward separate design of the surface and the interior of the adhesive material. Conventionally, when exploring the composition of adhesive materials, we automatically undertake the same modifications to the properties of the surface and of the interior whether this is desirable or not. One possible method of designing the two separately would be to divide the adhesive into a surface layer adhesive and beneath it a layer with the function of providing bulk.

Recently, in a further advance on this approach, a technology has been explored which would modify only the surface layer of the adhesive. In the future, developments of this kind will make it possible to design the surface and the interior separately, contributing not only to the advance of adhesion theory, but also giving great impetus to the reconciliation of opposing requirements.

4. Conclusion

Adhesive tape products are inconspicuous, but are used widely in industry because of their convenient features. We are convinced that the importance of adhesive tape products will continue to grow in future as they adapt to the multifarious functions required by industry.

Accordingly it is important to maintain a spirit of challenge through active efforts to develop new approaches in design philosophy, material technologies, manufacturing technologies, evaluation technologies, and other aspects. The design of adhesive tape products requires an approach straddling interface chemistry, polymer chemistry, material mechanics, fracture mechanics, rheology and other sciences, and there remain many unexplained areas in adhesive phenomena and adhesive theory. That there are many unexplained areas means also that there are many hidden possibilities, making this a very exciting and promising area of research.

In the future, to stimulate new demand, it will be necessary for customers to be made aware of the convenience and highly developed functions of adhesive tape products, and for manufacturers to accurately apprehend customer requirements. Our mission from now on will be to tie these efforts in skilfully with creation of environment-friendly products so as to continue with customer-centered product development.

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