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Bonding strength of adhesives and surface roughness of joined parts

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Abstract

The bonding strength of adhesives is influenced by the surface roughness of the joining parts. However, the magnitude of the influence has not yet been clarified because of the complexity of the phenomena. In this paper, it is found that an optimum value of the surface roughness exists with respect to the tensile strength of the adhesion. On the other hand, the peel strength shows no clear relationship with the surface roughness. The shear strength of the adhesion lies in the middle of the above two tendencies.

Keywords: Bonding strength; Surface roughness; Joined parts

1. Introduction

The significance of joining technology with adhesives is increasing in the field of manufacturing because it has many advantages compared with other joining methods. Concerning this technology, it has been said that the surface finish or surface treatment of the joining parts is very important for the securing of good adhesion, since the surface roughness is one of the important parameters that controls the state of the adhesion [1]. It has been pointed out that the bonding strength is influenced by the surface finish [2]. In 1996, Ikegami [3] examined the influence of the surface roughness on the bonding strength of adhesion and proposed a theoretical curve that shows a relationship between surface roughness and bonding strength. In his paper, he assumed two effects: (1) the effect of surface area; and (2) the notch effect due to the surface roughness. However, experimental verification seems to be not easy because of the scatter of the data.

The object of the present study is to clarify the influence of the surface roughness on the bonding strength of the adhesion.

2. Experiment

2.1. Experimental set-up

Three experiments were carried out: (1) an experiment on the tensile strength of adhesion; (2) and experiment on the shear strength of adhesion; and (3) an experiment on peel strength of adhesion.

Each test was designed and carried out according to the Japanese standard (JIS). Figs. 1–3 show the dimensions of the specimens for these three tests, respectively. The finishing condition of the specimens is as follows:

(1) Specimen for the tensile test. This is made from 1% carbon steel rod and its joining surface was finished by face milling, the roughness being controlled by changing feed. The tool marks of coupled joining surfaces are oriented so as to make a right angle with each other, as shown in Fig. 1.
(2) Specimen for the shear test. This is made from brass bar and its joining surface was finished by milling (1.6 t) or shaping (10 t), the roughness was being controlled by changing feed. The tool marks of coupled joining surfaces are oriented so as to make a right angle with each other, as shown in Fig. 2.
(3) Specimen for peel test. This is made from 0.5 mm thick brass sheet and its joining surface was finished by abrasive paper, the roughness being controlled by changing the grain size of the paper. The finishing marks of two mating surfaces are oriented so as to make a right angle with each other.

The specimens were cleaned using acetone before the adhesion process. The contact pressure was kept constant at 20 N/cm^2 during the cure. The time of the cure is either 24 h or 48 h. The tests were repeated five times for every experiment, and the maximum and the minimum data were discarded, the mean value then being calculated using the middle three data.

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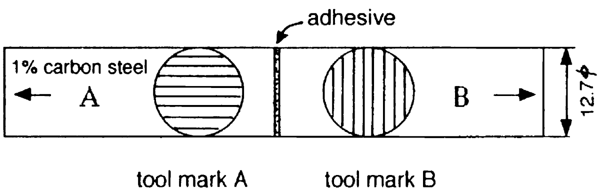

Fig. 1. Specimen for tensile strength test.

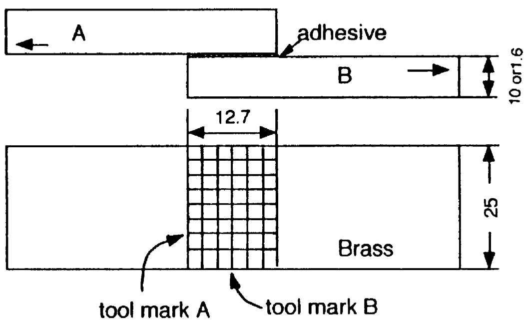

Fig. 2. Specimen for shear strength test.

The adhesives used in the experiments are as follows: (1) epoxy resin; (2) cyanoacrylate; (3) synthetic rubber type; (4) vinyl chloride type; and (5) cellulose type. An Amsler-type testing machine was used for measuring the bonding strength.

2.2. Experimental results

Figs. 4–8 show some results of the strength test. Figs. 4 and 5 show the relationship between the tensile strength of adhesion and the surface roughness for two adhesives (epoxy resin and cyanoacrylate, respectively). An optimum surface roughness that gives the maximum strength is clearly observed in these figures.

Figs. 6 and 7 show the relationship between the shear strength of adhesion and the surface roughness for two adhesives (epoxy resin and cyanoacrylate, respectively). The variation of the strength due to the change of surface roughness is lesser than that of the tensile strength.

Fig. 8 shows the peel strength of two adhesives (epoxy resin and vinyl chloride). No clear relationship is observed in this figure, and this is a common tendency for the other three adhesives.

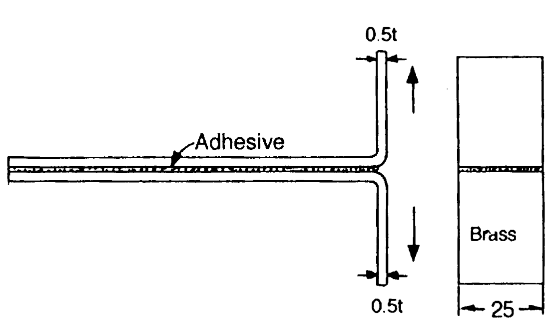

Fig. 3. Specimen for peel strength test.

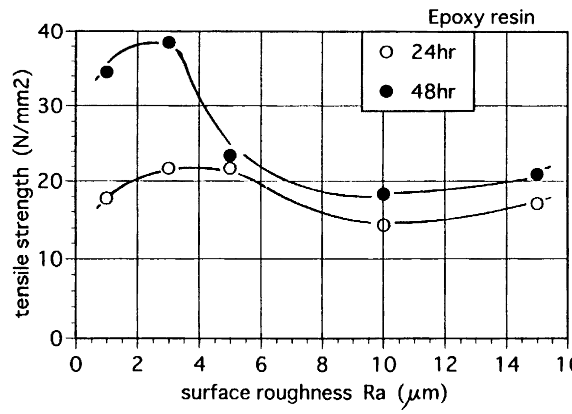

Fig. 4. Relationship between tensile strength and surface roughness. Adhesive: epoxy resin.

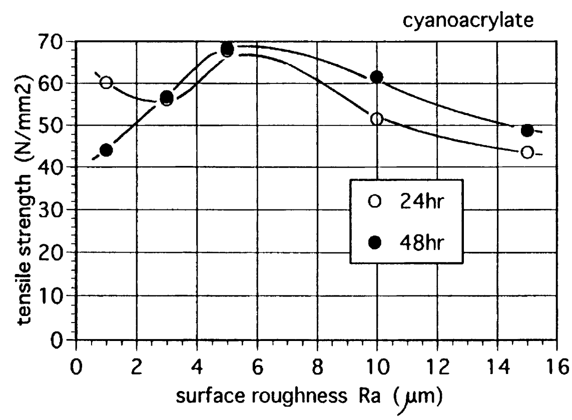

Fig. 5. Relationship between tensile strength and surface roughness. Adhesive: cyanoacrylate.

2.3. Discussions

Concerning the tensile strength of adhesion, it is clear that an optimum surface roughness exists that gives the maximum strength of adhesion for the five kinds of adhesives, the optimum surface roughness being in the range from 3 to

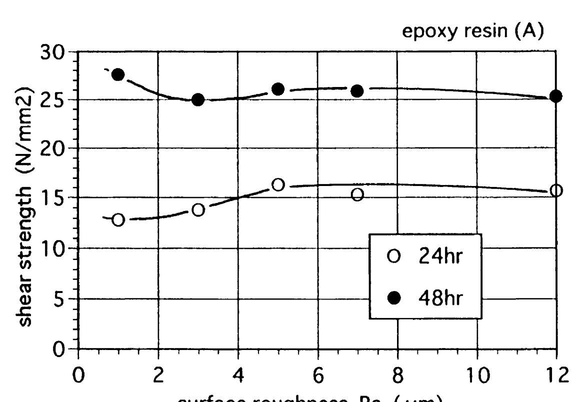

Fig. 6. Relationship between shear strength and surface roughness. Adhesive: epoxy resin.

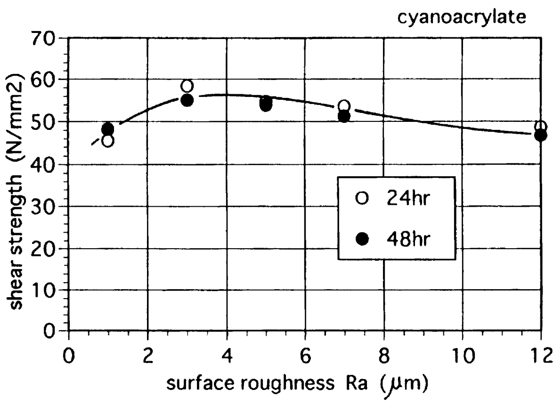

Fig. 7. Relationship between shear strength and surface roughness. Adhesive: cyanoacrylate.

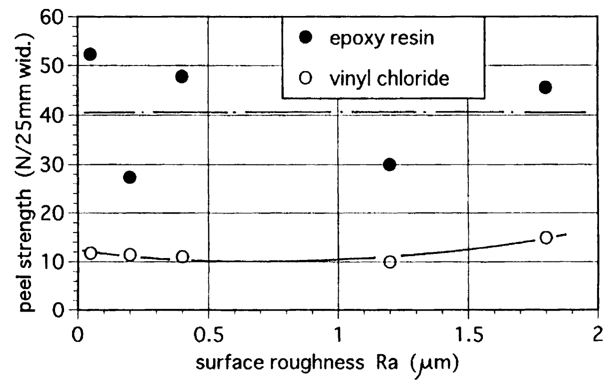

Fig. 8. Relationship between peel strength and surface roughness. Adhesive: epoxy resin and vinyl chloride type.

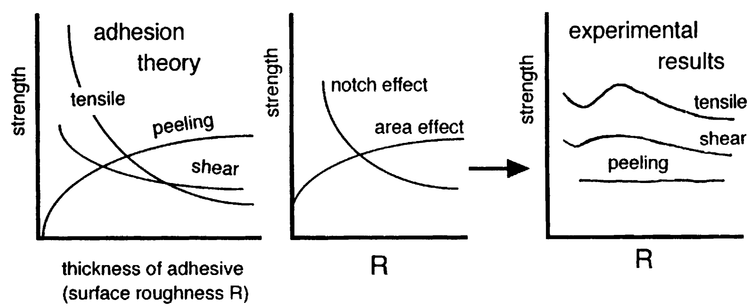

Fig. 9. Schematic illustration of bonding strength of the adhesion (as a combination of three factors).

6 μm Ra. In some cases (cyanoacrylate 24 h, cellulose type and vinyl chloride 48 h) the tensile strength was found to have a second increase in the range of small surface roughness ($Ra < 2\,\mu m$).

In the case of the shear strength of adhesion, a peak of the strength is virtually unobservable for three kinds of adhesives (epoxy resin, cyanoacrylate and vinyl chloride), but the cellulose type and the synthetic rubber type adhesives showed a peak, just as in the tensile test.

In the peeling test, no remarkable peak is observed with the change of the surface roughness.

Fig. 9 is a schematic illustration of why the strength curve takes a different form according to the kind of testing method. The left figure shows the theoretical value of the bonding strength of the adhesion. According to adhesion theory [1], the tensile strength is inversely proportional to the square of the thickness of the adhesives h, the shear strength is inversely proportional to h, and the peel strength is proportional to the 0.25th power of h. The surface roughness would have nearly the same meaning to the thickness of the adhesives because the directions of the tool marks are oriented so as to make a right angle to each other. This is the reason why the surface roughness R is also shown in this figure as the horizontal axis. The middle figure of Fig. 9 shows schematically the influence of the area effect and the notch effect on the bonding strength [3].

The real relationship between the surface roughness and the bonding strength will be the combination of the theoretical value (the left of Fig. 9) and the above two effects (the middle of Fig. 9). This is shown schematically in the right hand figure of Fig. 9. The various pattern of the curves that correspond to various test methods can be attributed to the difference of the magnitude of the combining three elements.

3. Conclusions

The bonding strength of adhesives (epoxy resin, cyanoacrylate, vinyl chloride, synthetic rubber and cellulose type) was measured in which the surface roughness of the mating surfaces was varied systematically. The findings are as follows.

1. An optimum surface roughness exists in the tensile strength of adhesion. The optimum value is in the range from 3 to 6 μm. In some cases (cyanoacrylate 24 h, cellulose type and vinyl chloride 48 h) the tensile strength has a second increase at very small surface roughness ($Ra < 2\,\mu m$).
2. No clear relationship is observed between the peel strength and the surface roughness for the five kinds of adhesives.
3. Concerning the shear strength, the tendency of the curve (shear strength–surface roughness) lies between those for the tensile strength and the peel strength.The tendency of the curve showing the relationship between the bonding strength and the surface roughness is explained by considering three factors: (1) the strength

based on adhesion theory; (2) the surface area effect; and (3) the notch effect due to the surface roughness.

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