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The Role of Metal Surface Asperities in Determining the Strength of Rubber to Metal Bonds

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The strength of the rubber to metal bonds has been observed to be dependent on the direction of failure propagation. Examination of metal surfaces revealed that the differences in the types of bond failure, and hence the bond strength, when the direction of failure propagation in the 90° peel test was reversed was associated with the asymmetrical structure of the asperities on the metal surface. These asperities, with different slopes on their opposite sides, gave rise to different degrees of difficulty in dislodging the rubber from the crevices, thus giving different types of failure. Peeling from sides having the steeper slope resulted in bulk failure and hence a higher bond strength while peeling from the side with gentle slope resulted in a combination of rubber and interfacial failures, thus a lower bond strength. This was confirmed from the scanned of the metal surfaces and also from model experiments.

Rubber to metal bonding forms a crucial part of rubber technology. A wide range of components, used in both mechanical and civil engineering, rely heavily on the formation of strong bonds between the rubber and metal. Poor bonding inevitably leads to a poor performance of components and may consequently lead to failure of the system. Thus, the ability to produce strong, permanent bonds between rubber and metal has played a vital part in the advancement of rubber as an engineering material.

The early attempts to bond rubber to metals were by mechanical means, but inevitably these proved to have severe limitations. As early as the 1850s, an ebonite interlayer was being used commercially for soft rubbers and this method continues to be used for some applications. Since then, numerous techniques have been developed to bond rubber to metal, but the most convenient and versatile means has been with the use of proprietary bonding agents. These are mixtures of an undisclosed composition, consisting of reactive ingredients suspended or dissolved in organic solvents, which are able to react with the rubber under pressure and/or heat.

Bonding rubber to metal using proprietary bonding agents depends on several factors. These include the base polymers[1–3], compounding ingredients[3,4], moulding conditions[5], bonding systems[5] and product designs[6], all of which have been well-documented.

The metal surface preparation is also known to influence the rubber to metal bonding[5,7]. Although its importance has been acknowledged, little datum on the effect of surface preparation on rubber to metal bonding is available. Cutts[5] has investigated some of the effects of different surface treatments on bonding and noted that abrasive cleaning using grit blasting is an important factor in producing a good bond. The effects of surface asperities was, however, not investigated. This paper describes work on the effect of surface asperities on the strength of rubber to metal bonds.

EXPERIMENTAL

Materials and Formulations

The base polymer used was natural rubber and the formulation is shown in *Table 1*.

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TABLE 1. FORMULATION

Ingredient	Parts
Rubber (SMR L)	100
Zinc oxide	5
Stearic acid	2
Carbon black (N550)	45
Process oil[a]	4.5
Antioxidant, HPPD[b]	3
Antiozonant wax[c]	2
CBS[d]	0.6–2.5
Sulphur	0.6–2.5

[a] Dutrex 737 MB, Aromatic process oil

[b] N-(1,3-dimethylbutyl)-N'-phenyl p-phenylenediamine (Santoflex 13)

[c] Antilux 654

[d] N-cyclohexylbenzothiazole-2-sulphenamide

Vulcanisates were prepared from masterbatches which were mixed in a 1-litre capacity laboratory internal mixer. Vulcanising agents were added on a two-roll mill which was maintained at about 60°C. Moulding was carried out immediately after the addition of the vulcanising agents.

Preparation of Testpieces

The preparation of testpieces involves cleaning the metal plates, followed by bonding them to the rubber.

The metal plates were cleaned prior to bonding in accordance with BS code of practice, *CP 3012 : 1972*. First the metal plates of 60 × 25 × 3 mm were soaked in 1-1-1 trichloroethylene to remove all greases and oils. The grease-free plates were then blasted with abrasive chilled iron grit of grade G18, and subsequently soaked in fresh 1-1-1 trichloroethylene for further degreasing.

The cleansed metal plates were removed from the solvent and left to dry before they were painted with the bonding agent. A layer of primer coat of a proprietary bonding agent (Chemlok 205) was first applied to the test area (50 × 25 mm) of the metal plates *(Figure 1a)*. The painted metal plates were left to dry at room temperature for about 15 min before being painted with the top coat of the bonding agent (Chemlok 220), and left to dry in a dust-free atmosphere.

Moulding of testpieces was carried out at 150°C up to the time that they gave maximum torque on the rheometer (typically about 12 min). The cleansed, dust-free metal plates were inserted into the mould together with the rubber compound prepared earlier. Bonding occurred during the vulcanisation process. A typical testpiece prepared is shown in *Figure 1b*. It is basically a modified *B.S. 903 (Part A21: 1974)* rubber to metal bond strength testpiece, consisting of a rubber strip of about 250 mm length, 25 mm width and 6 mm thickness at the test area bonded to the metal face of area 50 × 25 millimetres.

Similar bond strength testpieces were also made by cutting from a commercially produced rubber bearings. The dimensions of the cut testpieces were the same as the moulded testpieces *(Figure 2)*.

Testing

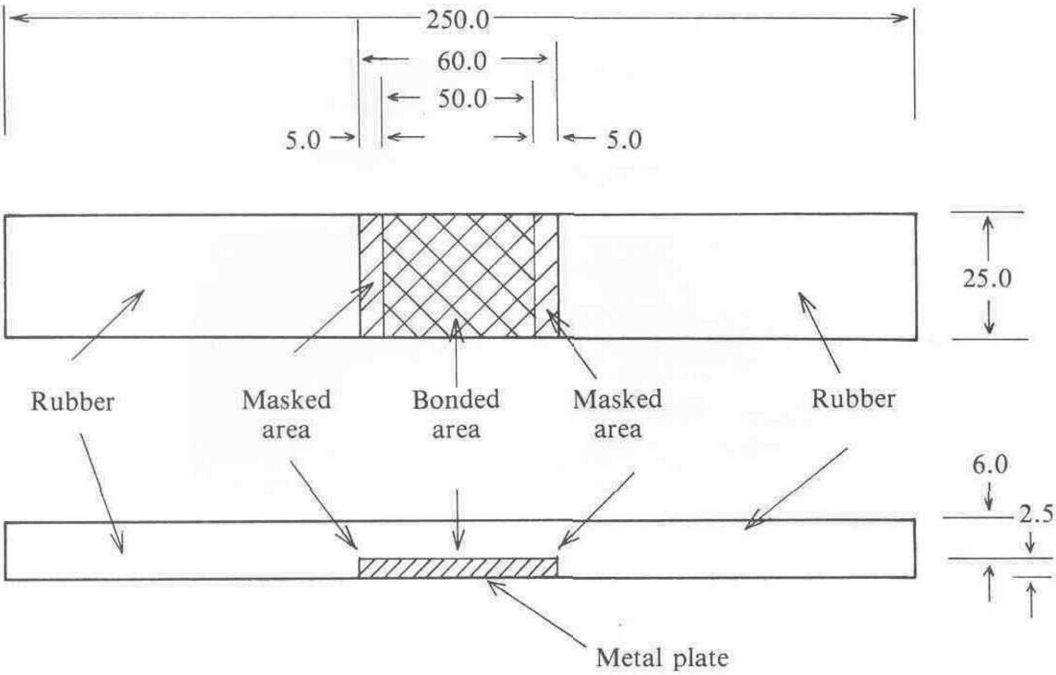
The 90° peel test was used as a method of assessment of the bond strength of rubber to metal. The test was carried out in accordance with *B.S. 903: Part A21: 1974*.

The fixture of the 90° peel test (or bond test) is shown in *Figure 3*. The metal plate was fixed rigidly into the slot of the jig for the testpiece. Peeling was achieved by gripping and pulling one of the free ends of the rubber until the failure propagated up to the middle of the bonded part, after which the direction of peeling was reversed by pulling the other end of the testpiece. The bond strength was taken as the maximum force required to debond the rubber divided by the width of the bonded area.

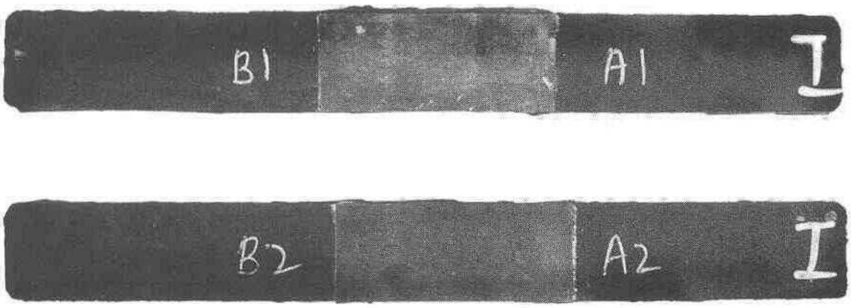
All testing was carried out at room temperature (23°C) on samples which were kept at least 16 h but not more than 72 h at room temperature prior to the test.

Scanning of Metal Plate

Examination of the metal surfaces was carried out using the scanning electron micro-



a. Plan and side views with dimensions



b. Moulded samples

Figure 1. Rubber to metal bonding testpieces.

scope (SEM). Prior to scanning, the metal plates which had been debonded from the rubber were thoroughly cleaned, first by soaking in toluene to remove the remnants of rubber, followed by washing with 1-1-1 trichloroethylene to remove traces of bonding agent and grease. The metal plates were cut into suitable sizes for the SEM cell and cleaned with acetone before the scan.

RESULTS AND DISCUSSION

The Rubber to Metal Bond Strength of a Laminated NR Bearing

Laminated rubber bridge bearings consist of thick interlayers of rubber and metal plates *(Figure 2)*. During production, the time taken to mould the bearing is usually longer than the

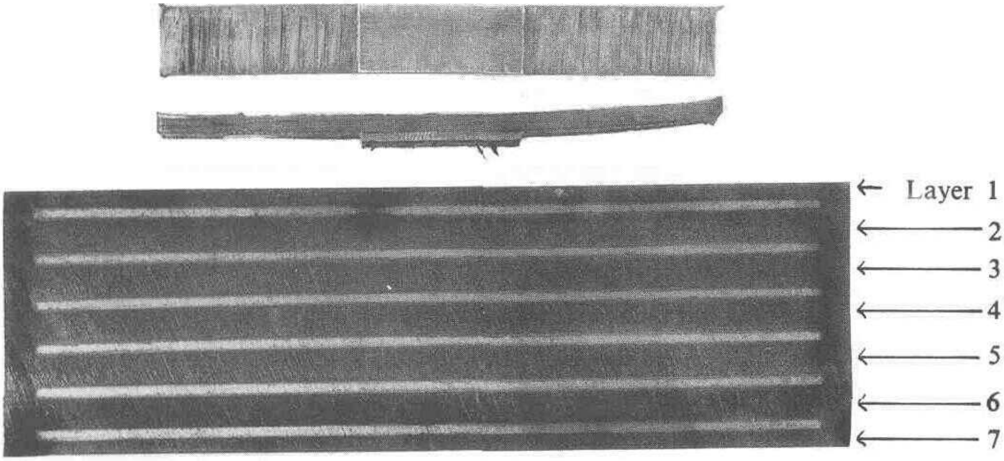


Figure 2. Cut rubber-bearing pad showing metal plates and bond strength testpiece (top).

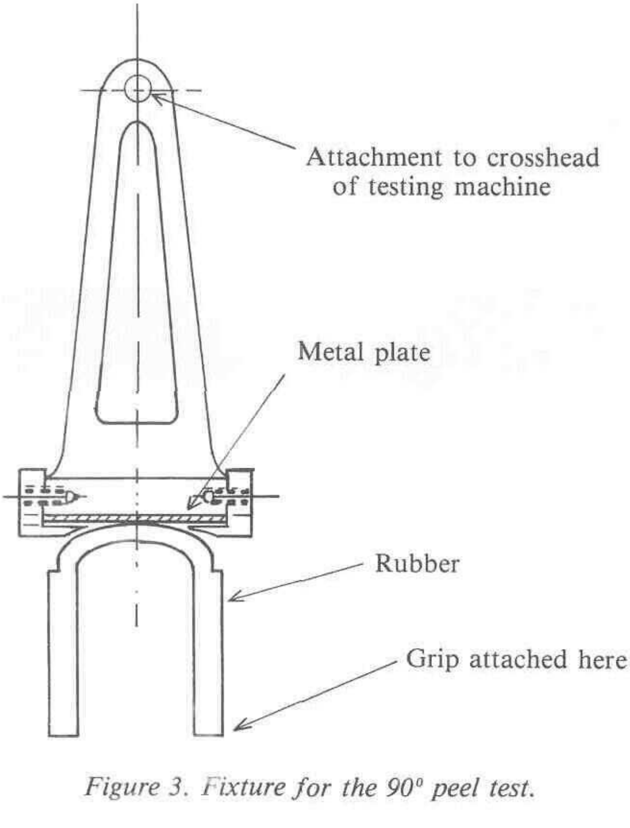


Figure 3. Fixture for the 90° peel test.

cure time of the rubber as obtained from the rheometer. A longer time is needed to allow the heat to reach the interior part of the bearing because of the poor conductivity of the rubber.

The physical properties of rubber are drastically affected by prolonged exposure to heat. The outer layers of the bearing will be most affected. A study carried out[8] showed that rubber properties like hardness, compression set and relaxed modulus (MR100) were affected by the prolonged exposure to heat, with properties improving towards the interior part of the bearing. The rubber to metal bond strength was, however, not significantly affected. This is shown in *Figure 4,* where the bond strength values are plotted against the rubber interlayers for a typical rubber bridge bearing having six metal plates. Rubber layers *1* and *7* refer to the top and bottom cover layers, while layers *2* to *6* represent the intermediate layers. The two different values at layers *2* to *6* for a particular curve represent the results obtained from different metal surfaces of that particular layer. Some scatter in the results was observed, but the general trend showed an insignificant difference in the bond strength values due to the prolonged heat treatment of the rubber. The bond strength values were, however, observed to be markedly affected when the direction of failure propagation changed. This is clearly shown by the two different curves in *Figure 4,* which consist of results obtained from the same testpiece, pulled from two opposite directions.

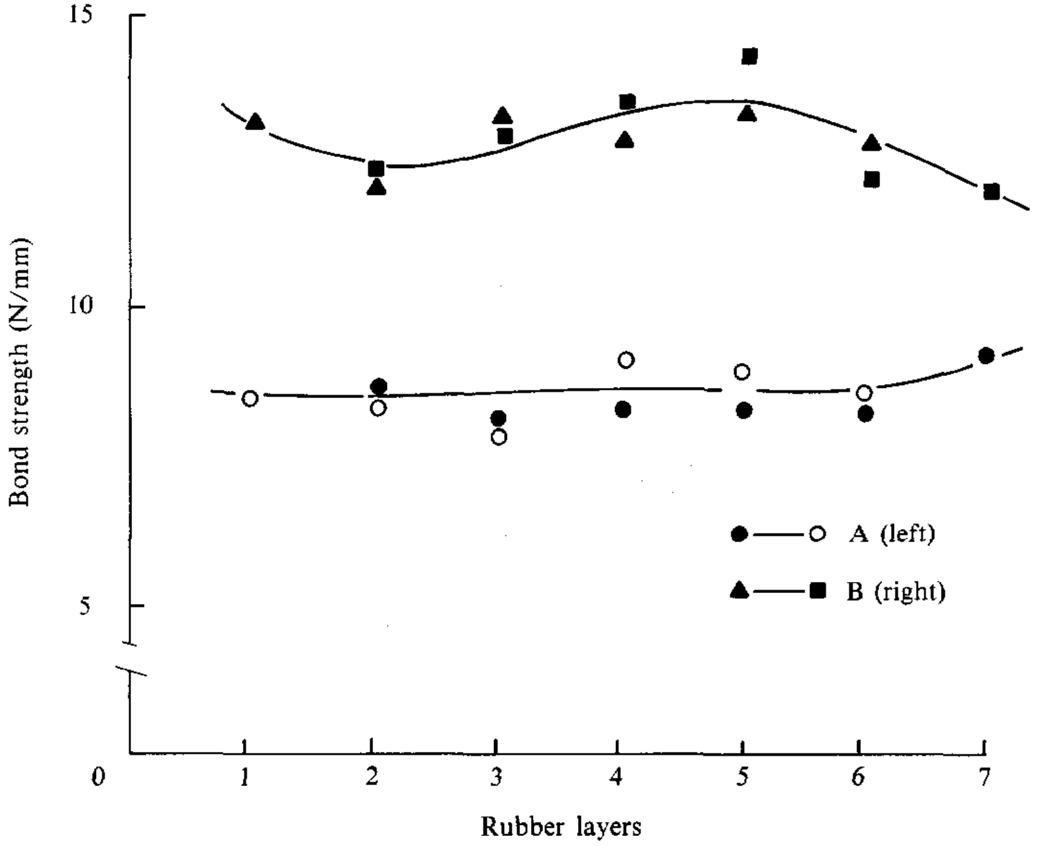


*Figure 4. Peel strengths as a function of rubber layers of a laminated bearing pad (*A *refers to pulling from the left side and* B *refers to pulling from opposite direction).*

The values shown in *Figure 4* are not necessarily typical results. These values were randomly observed; some showed marked differences while some were independent of the direction of failure propagation. However, when there were differences in bond strength, the difference in values varied from about 50% to over 100%.

Influence of the Direction of Failure Propagation on Bond Strength

The commercial rubber bearings showing bond strength changes with the direction of failure propagation in a 90° peel test were interesting. Experiments were carried out to seek an explanation to the phenomenon. After a series of trial experiments, the effect was successfully reproduced when the direction of grit blasting during the abrasive cleaning of the metal plates was altered.

During the abrasive cleaning/grit blasting of the metal plates prior to the application of the proprietary bonding agent, the nozzle of the blasting machine can be varied according to the operator's convenience. For laboratory studies, the nozzle held at perpendicular to the surface of the metal to be cleaned was found to be more efficient compared to that held at a more acute angle. This partly explains the failure of initial work to reproduce the effect where cleaning of metal surfaces was done using normal laboratory procedures.

Typical results on the influence of the direction of failure propagation on bond strength are shown in *Figure 5*. The histograms on the left *(A)* and right *(B)* respectively refer to the lower and higher values of the bond strength obtained from the same testpiece but pulled from the opposite direction. The average bond strength values obtained from over a dozen

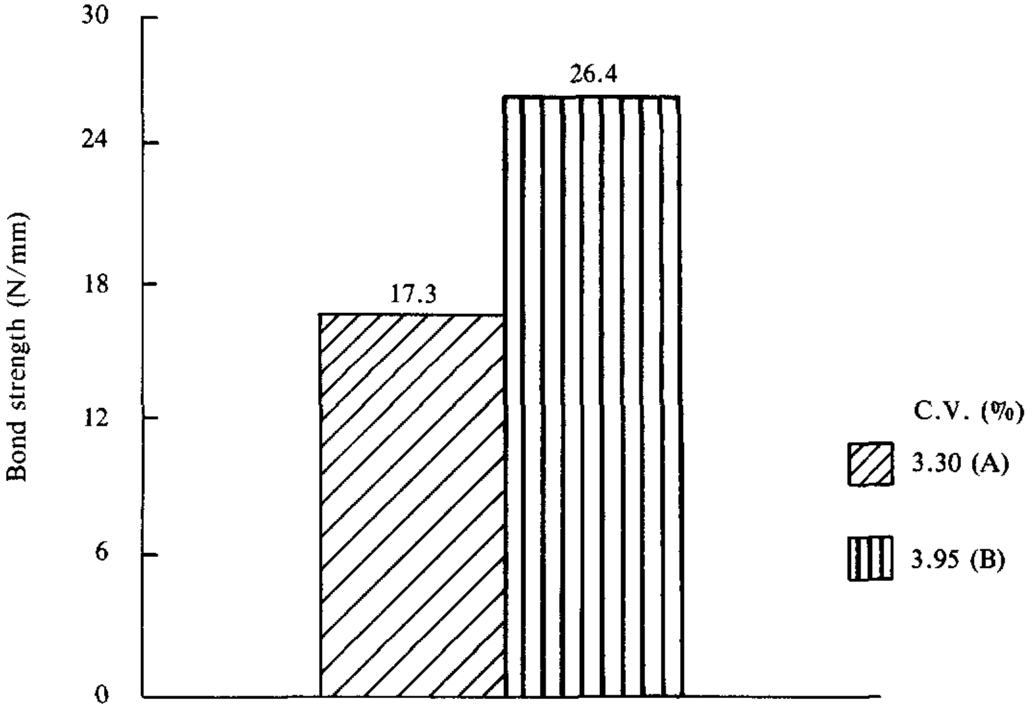


Figure 5. A typical difference in bond strength values when the direction of failure propagation changes for rubber crosslinked using conventional system.

identical testpieces, together with their coefficients of variance (C.V.) are given. The difference of over 50% in bond strength was observed when the direction of failure propagation changed. These results have been fairly consistent, with differences of 100% occasionally being observed with individual samples.

Similar results were observed regardless of the vulcanising system used. This is clearly shown in *Figure 6,* where the bond strength values of rubber crosslinked using the conventional (CV), semi-EV (SEV) and efficient (EV) systems are given. The histogram *A (Figure 6)* refers to the lower values of the bond strength obtained from a particular testpiece pulled along one direction while that marked *B* refers to the corresponding higher values obtained from the same testpiece, but pulled in the opposite direction. Nearly 100% difference in values was observed with the conventional system, when the direction of failure propagation changed, while smaller differences were observed with the SEV and EV systems. The differences were due to the difference in tear strengths of the rubber, with the conventional system giving the higher values *(Table 2).*

The type of failure also changed when the direction of propagation was reversed. In all cases, the type of failure associated with the higher bond strength values was that of rubber *(R)* failure while those of the lower values were a combination of rubber-cover cement *(RC)* and *R* failures[9]. The *R* type of failure leaves

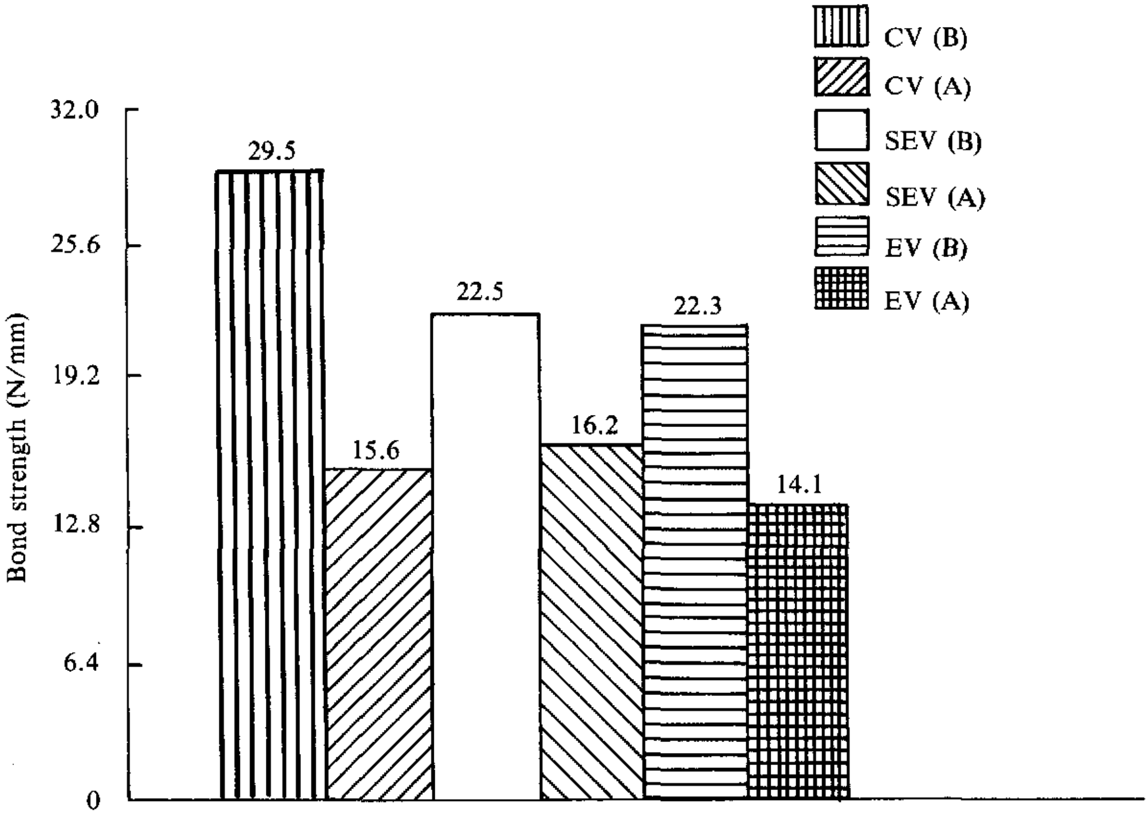


Figure 6. Bond strengths of rubber crosslinked using CV, SEV, and EV vulcanising systems. (A: pulled from the right, B: pulled from the left).

TABLE 2. HARDNESS AND TEAR STRENGTH (CRESCENT) OF RUBBBER

Vulcanising systems CBS/S ratios	Conventional 0.60/2.50	SEV 1.23/1.23	EV 2.50/0.60
Hardness (IRHD)	58.0	59.0	58.0
Tear strength (N/2 mm)	259	226	210

thick lumps of rubber on the metal plates while the combination of *R* and *RC* leaves a series of well-spaced thin waves of rubber. This is shown in *Figure 7* where a series of well-spaced waves of rubber characterising a combination of *R* and *RC* types of failure can be seen on the right half of the metal while that of the left half has thick lumps of rubber corresponding to the *R* type of failure.

Metal Surface Asperities

The surfaces of metal laminates used in a rubber bridge bearing prior to abrasive cleaning by grit blasting are fairly smooth *(Figure 8a)*. Even at the micro-level, no asperities were observed. The abrasive cleaning changed the metal surface drastically. Grit blasting using iron grit of size G18 for instance, changed the smooth metal surface shown in *Figure 8a* to that of *Figure 8b*. The grit blasting process, apart from removing a layer of the metal surface, created a surface having a larger area for the rubber to adhere to.

The sizes and types of micro-asperities or craters formed after grit blasting depend on the size of the iron grit, the rate and angle of impingement. Tilting the nozzle of the grit blasting machine relative to the metal surface to be cleaned, gives micro-asperities having a gentle slope on one side and a steeper slope on

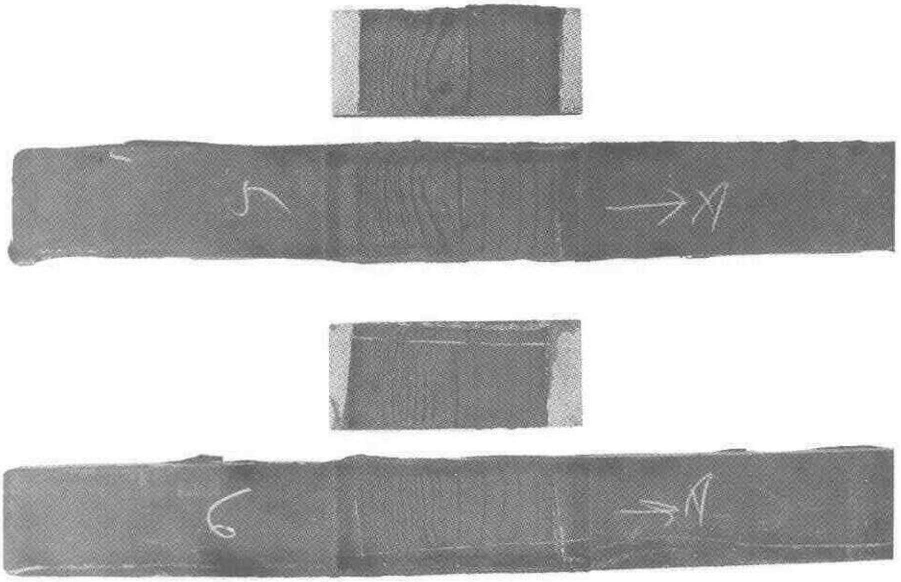
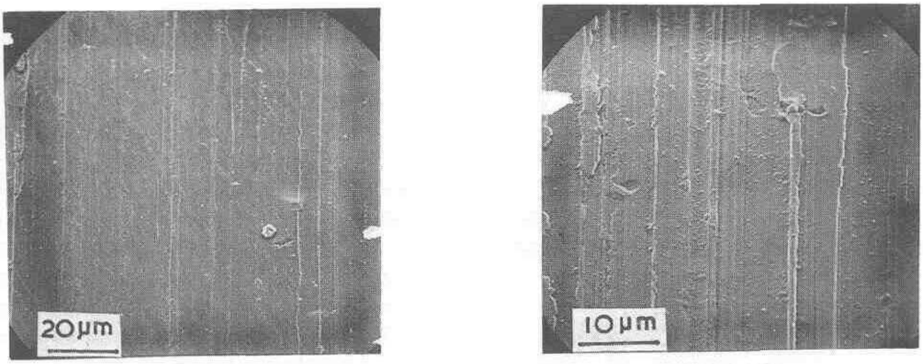
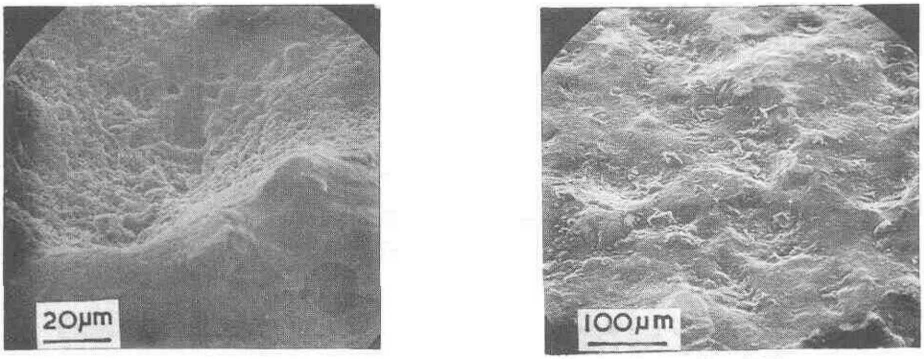


Figure 7. The types of failure observed when the direction of failure propagation changes. (Left half: rubber failure, right half: rubber-cover cement failure).



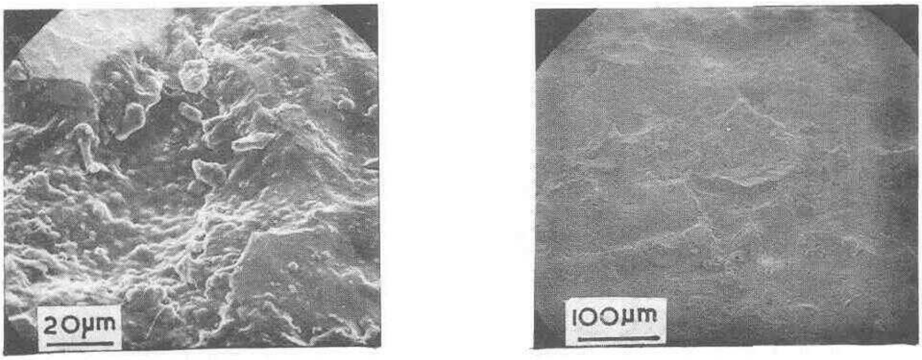
(1) × 450 (2) × 100

a. Fresh unused surface



(1) × 450 (2) × 100

b. Surface grit blasted vertically



(1) × 450 (2) × 100

c. Surface grit blasted at inclined angle

Figure 8. Magnified views of metal surfaces showing different types of asperities.

the opposite side. At an angle of impingement of about 45° for instance, the surface of metal produced is as shown in *Figure 8c*. The surface appears rugged, with micro-asperities of slopes with different gradients. This is in contrast to the metal surface obtained when the angle of impingement is at 90° *(Figure 8b)*. Thus, a variety of surface asperities can be obtained during abrasive cleaning by grit blasting, depending on the way it is carried out.

Dependence of Bond Strength on Surface Asperities

The micro-asperities shown in *Figure 8c* are typical of a metal surface obtained when the angle of impingement of iron grit during the abrasive cleaning is about 45° relative to the metal surface. This type of asperity, one side having a gentle slope with the other being much steeper, was observed to give a variation in the bond strength values when the direction of failure propagation changed. Analysis of the peel test results and pictures of the metal surface taken using the SEM suggest that the higher bond strength values correspond to peeling from the direction of the steeper slope while the lower values correspond to peeling from the direction of the gentle slope. Peeling from the direction of the steep asperity slope was more difficult and needed higher force since the rubber was trapped within the crevices. This resulted in thick lumps of rubber being left on the metal plates, due to failure in the bulk of the rubber. This was in contrast to the type of failure which occurred when peeling was carried out from the direction of the gentle slope of the micro-asperity, where the failures were a combined *R* and *RC* type. The latter type gave a relatively low bond strength and left thin waves of rubber on the metal surface.

Schematically, the situation could be represented by a model as shown in *Figure 9*. The rubber is being pulled from two opposite directions: one from the direction of the steep slope (side *B*) while the other from the opposite direction (side *A*). The directions of failure propagation are indicated by the arrows.

Pulling from side *B* will require higher forces since part of the rubber is trapped in the crevice and difficult to dislodge due to the steep slope

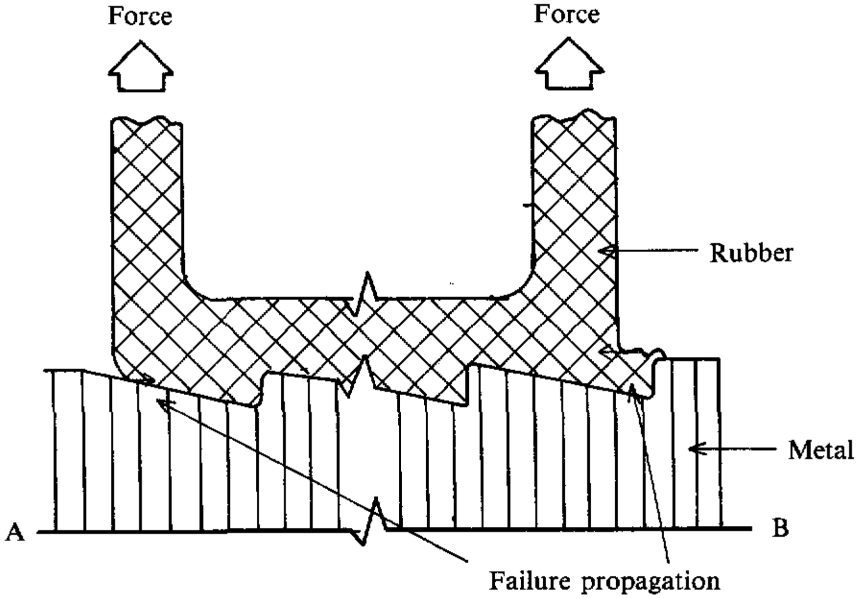


Figure 9. Schematic representation of bond failures due to peeling from two opposite directions.

of the asperity. The force applied to debond the rubber will consequently cause bulk failure, with thick lumps of rubber left behind. This is in contrast with peeling from the reverse direction (side A) where dislodging the trapped rubber is comparatively easier due to the gentle slope of the micro-asperity. A comparatively lower force will be needed to dislodge the rubber when pulling from this side. A combination of interfacial and rubber failure occurs, leaving thin waves of rubber on the metal plate.

The model given is consistent with the experimental observations and it has also been verified by model experiments. The experiments involved machining a metal plate to produce micro-asperities bounded by a steep slope on one side and a gentle slope on the opposite side. The asperities produced by machining are shown in *Figure 10.* These surface asperities were not obtained by sandblasting as normally done for abrasive cleaning, but machined at a certain angle so that the desired asperities were formed. The machined metal plates were washed with solvents and painted with proprietary bonding agents, prior to vulcanisation. Peel tests were carried out on these samples and results obtained *(Figure 11)* were similar to those observed earlier whereby the peel or bond strength values were higher when peeling was initiated from the direction having a steeper slope compared to peeling from the opposite direction. The types of bond failure with these samples were the same as that observed earlier, in which thick lumps of rubber were left on the metal plates when peeling was initiated from the steeper side of the asperity while thin waves of rubber or sometimes clean surface (*RC* failure) resulted when peeling was initiated from the reverse direction *(Figure 12).*

The differences in bond strength obtained from the model experiment *(Figure 11)* when the direction of failure propagation was changed were not as marked as those of the samples prepared with metal plate cleaning by grit blasting. This is presumably because the asperities formed by machining were fairly large compared to the grit blasted surfaces, more asperities per unit area were present in the latter. Furthermore, the steep slope of the asperities was steeper when the metal was grit blasted *(Figure 8).* However, the differences observed with model experiments were large enough (25% to 50%) to indicate that the gradient of the micro-asperities caused the marked differences in the bond strength values when the direction of failure propagation changed.

CONCLUSION

Rubber to metal bond strengths can be observed to be dependent on the direction of failure propagation. The 90° peel test gave about 100% difference in the bond strength when the direction of failure propagation was reversed. The higher value of bond strength was associated with R failure while the corresponding lower value was associated with the combined effects of R and RC types of failure.

Examination of the metal surfaces revealed that the differences in the types of bond failure, and hence the bond strength, when the direction of failure propagation was reversed was associated with the shape of the micro-asperities on the metal surfaces. These asperities, possessing different slopes on their opposite sides, resulted in varying degree of difficulty in dislodging the rubber at the interface, hence giving different types of failure. Peeling from the side having the steeper slope resulted in bulk failure of the rubber and hence higher bond strength while peeling from the side with gentle slope resulted in a combination of rubber and interfacial failures and hence lower bond strength. These findings were reinforced by the scanned of the metal surfaces and also from model experiments whereby rubber was bonded to a metal plate which had been machined to produce crevices bounded by sides having different slopes in the direction of failure propagation.

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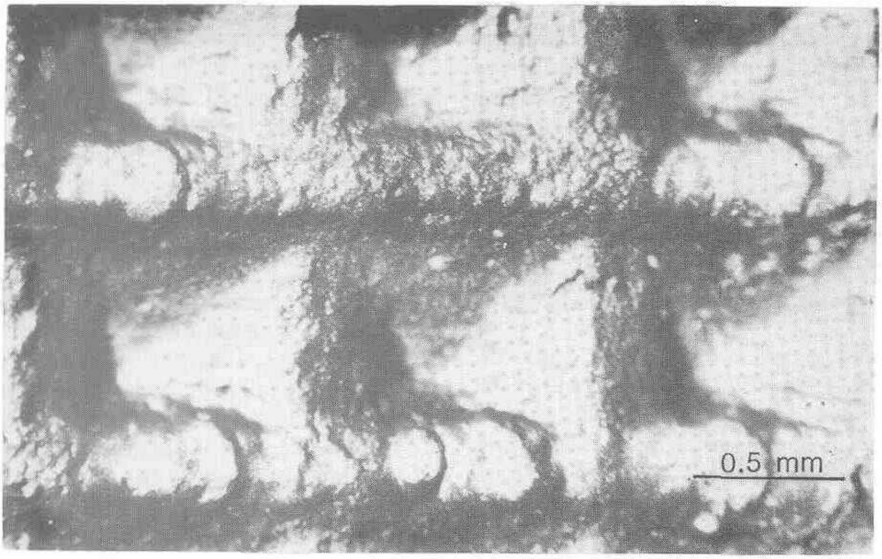
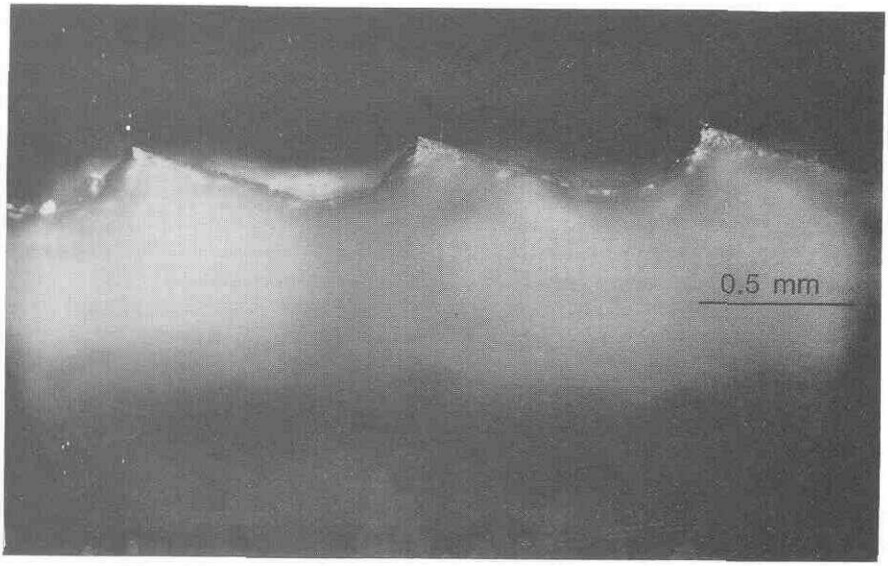


a. Plan view (× 40)



b. Side view (×40)

Figure 10. Magnified views of machined metal surfaces showing asperities.

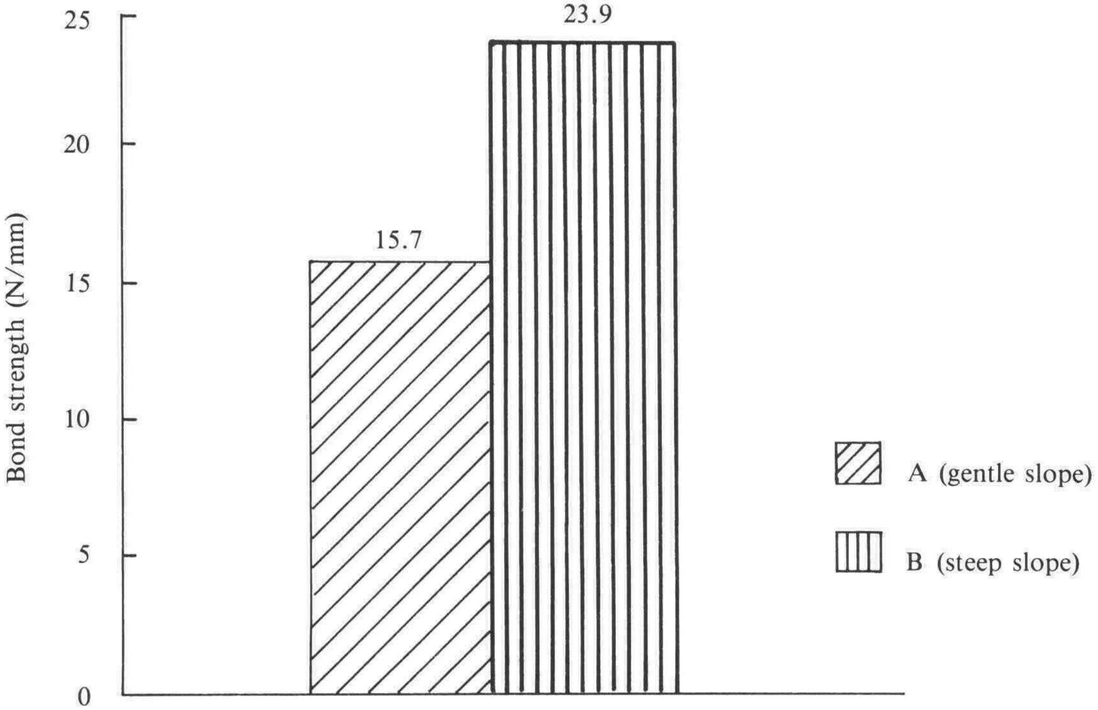


Figure 11. Bond strengths of rubber bonded to machined metal plate, and pulled from two opposite directions.

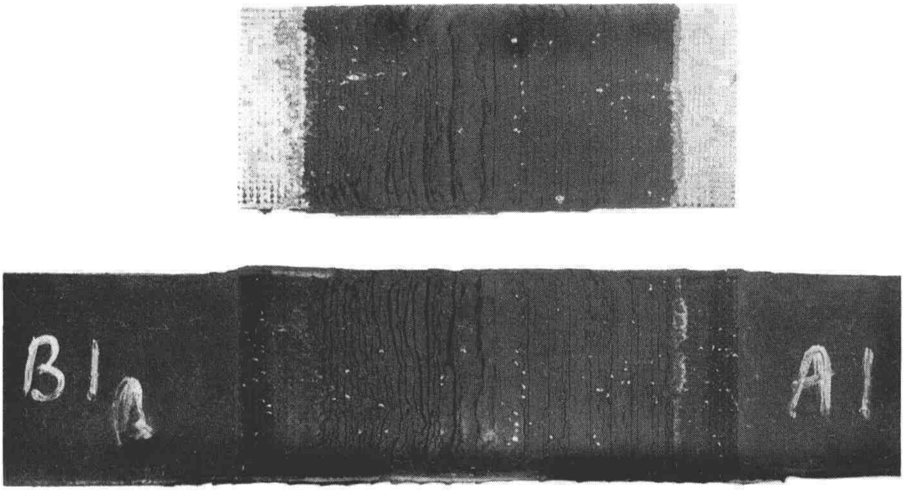


Figure 12. Test sample showing different types of bond failure with machined metal plate.

REFERENCES

1. ALSTADT, D.M. (1955) Effect of Rubber Polarity. *Rubb. Wld., N.Y.,* **132(2)**, 221.
2. DE GREASE, W.M. (1960) Compounding Elastomers for Rubber to Metal Adhesion. *Rubb. Age, N.Y.,* **87**, 1013.
3. COX, D.R. (1969) Some Aspects of Rubber to Metal Bonding. *Rubb. J.,* **151(51)**, 73.
4. HASSAN, A.A. AND HEPBURN, C. (1979) Failure and Fatigue of the Rubber to Brass Bond. *Proc. Int. Rubb. Conf. Venice 1979.*
5. CUTTS, E. (1981) *Developments in Adhesives-2 (Kinlock, A.J. ed).* London: Applied Science Publishers.
6. BUCHAN, S. (1959) *Rubber to Metal Bonding,* 2nd edition. London: Crossby, Hockwood.
7. COX, D.R. (1968) Some Aspects of Rubber to Metal Bonding. *Rubb. J.,* **157**, 49.
8. ALIAS BIN OTHMAN (1986) Unpublished data. Rubber Research Institute of Malaysia.
9. BRITISH STANDARDS INSTITUTE (1974) Determination of Rubber to Metal Bond Strength. *B.S. 903: Part A21.*