CONCRETE BLOCKS WITH USED TYRES

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ABSTRACT

It is vital to remove ice on the roads, particularly motorways, in cold regions. Rubberized roads have proved to be free of black ice because passing vehicles crack and disperse the ice. Few motorways, however, have been covered with rubber yet because the surface rubber in current use is subjected to rubber separation and/or crumbling; and it may offer a slippery surface to moving vehicles when wet.

Using old tyres presents many other problems. As recycling was encouraged, trials have been carried out to seek effective techniques to utilize these discarded tyres. To overcome thickness differences, processes of granulation and re-solidification are usually applied in the manufacture of industrial used-tyre products. This procedure suffers from high cost and low strength of the product.

Concrete blocks combined with solid pieces of used tyres that are not granulated may solve these problems completely. The total block size can be easily standardized with concrete despite the differing thickness of the old tyres. In addition, limiting the size of the blocks can reduce the thermal discrepancy at the edges. With regard to skidding, the tread patterns of tyres are effective in removing water, enhancing the apparent coefficient of friction when wet. Above all, the rubber in used tyres is durable and inexpensive.

Success with these blocks made of used tyres depends on factors such as block size and the means by which the rubber comes into contact with the road surface. A concreting method can be applied to form the blocks and attaching the concrete to the rubber. Asphalted adhesive plates are pasted on the rubber pieces cut from old tyres. Fresh concrete is placed directly onto these plates. As the concrete hardens, the adhesive strength increases. The focus of this study centres on those factors that influence the shear strength of the surface rubber at high temperatures in hot summer; obtaining data on the effects of block size; and measuring the apparent coefficient of friction of the blocks. The experimental conditions for shear strength have been arranged for factorial analysis.

1. INTRODUCTION

1.1 Background

A rubberized road surface is not only able to prevent black ice (Inuzuka and Nagata, 2000) and skidding accidents in winter: it also will reduce the noise level caused by tyres. In spite of many trials, a practical means to keep the rubber on the motorways has not been devised yet due to three main difficulties associated with current practice:

- Rubber separation is due to different rates of thermal expansion between the surface rubber and its base. Exfoliation caused by repetitive cycles of temperature changes starts at the edge and extends inward.

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- Skidding accidents take place because the coefficient of friction of rubber drops considerably when the rubber gets wet. The longer section of rubber will reduce the construction cost, but skidding distance increases.
- Construction cost is high because rubber must be specially produced to be durable in severe weather conditions. Stabilizing rubber on road surfaces is also difficult when the traffic is heavy.

Piles of used tyres are the cause of two main environmental problems:
- Foul, still water in a tyre is a breeding ground for mosquitoes, and
- Air pollution results when tyres burn and toxic gases are emitted.

To utilize these large quantities of discarded tyres, the current solution is either to burn them in a special furnace or embed them under the roads. Besides a number of processing factories are limited. In this situation and to reduce transportation costs, processors wait until large piles of these low-value rubber materials have accumulated. In addition to these concerns, illegal dumping is a controversial subject. The circulation of used tyres in the trade is based on a negative unit value so that one old tyre starts out with a negative valuation to be paid by an end user, approaching the final price to burn in the furnace. Therefore it is difficult to prevent illegal dumping. If discarded tyres can be utilized to make more valuable materials, these problems might disappear. Being durable, these tyres can play a utilitarian role when properly designed, as shown in Fig. 1.



Figure 1. Blocks designed with non-granulated used tyres.

1.2 Problems

Thus the practice of covering pavement with granulated tyre rubber began ten years ago. Only a limited number of tyres, however, are recycled to produce these rubberized paving blocks. Although recycling is encouraged, paving blocks are applied mainly to pedestrian walkways. A solid plate made of granulated tyres is not only weak on motorways: it is also expensive due to the manufacturing processes required for granulation and solidification. An old tyre may be of varying thickness but a manufactured paving block must have a flat surface. To overcome this random thickness, an industrial process to granulate used tyres (i.e., turn them into grains) and recombine these smaller, more or less uniform grains has been applied and become normal practice.

This process has three main drawbacks:

- The relatively high cost of two different processes: granulation and solidification.
- The end product of an assembled granulated tyre is mechanically weak.

In addition, it is problematical to hold rubber on motorways subjected to heavy traffic. The thermal expansion of rubber is over eight times that of other base materials, such as concrete, so that the repetitive thermal cycle will cause severe stresses between the rubber and the base. To attach the rubber to the base material, resin paste has been used in conventional practice as an adhesive. The adhesive is applied to hardened concrete and the rubber tyre material has to be selected so that the thickness of each piece is approximately constant; otherwise the height of finished blocks will vary randomly. When the adhesive layer is of resin paste and flat, separation or exfoliation seems inevitable. In addition to repetitive stress due to circadian thermal cycles, traffic loads increase the shear between rubber and concrete. After separations were found in most trials, much higher values of shear stresses were assumed to approximate the actual stresses. To try to increase the adhesive strength, experiments have been carried out with a variety of resin adhesives. Since recycling of used tyres began to be encouraged, many have been used to cover the motorways with tyre rubber cemented on with a strong resin, only to fail as shown in Fig.2.



Figure 2. Exfoliation of a rubber piece.

1.3 Solutions

1.3.1 Solid rubber piece

Consequently the solid pieces cut from used tyres should be applied to certain roads because they will not only overcome the aforementioned drawbacks: they will also circumvent the dual manufacturing processes. A process in which the rubber is cut without granulation is much simpler than two successive processes; thus much simpler facilities may be satisfactory to shape the rubber parts of the blocks. Besides, a solid piece is much less likely to crumble or disintegrate. Another advantage of the recommended practice: one can reduce the size of the blocks, increasing the number of joints in a given distance, which, due to the increased number of joint lines, will raise the apparent coefficient of friction.

1.3.2 Concrete
One of the main functions of the concrete in a block is to assure that the thickness of successive blocks will remain constant. The thinner it is, the more effective the concrete will be for this purpose. Another function of concrete is to stabilize the rubber pieces on a road surface so that, ideally, the thickness will be enough to resist shear as well as suction from passing vehicles, which conventional blocks are expected to do.

1.3.3 Adhesion
With regard to the large thermal variations that are the cause of end separation, the magnitude of the shear strength seems to be less important than the repetition rate of passing vehicles. Therefore an asphalt plate was interleaved between the rubber piece and the concrete, which is placed directly on the asphalt adhesive. Eventually the adhesive strength will rise to a level that ensures stabilization.

1.3.4 Joints
The main function of the joints is to prevent the rubber pieces from moving horizontally. Besides, the joints between the rubber pieces should play a role in obtaining a level of coefficient of friction for the tyres of passing vehicles. Rubber pieces made from used tyres are able to remove water much faster than a plain rubber surface so that the coefficients of friction when wet are relatively high: over 0.28 on the blocks.

1.3.5 Other considerations
The point of partially paving roads with rubberized blocks is that one anticipates that only the section of the road surface on which the wheels of the vehicles run will be of rubber, not necessarily the whole motorway. Even discontinuous rubber pieces, as shown in Fig. 2, are effective in removing surface ice. The apparent coefficients of friction between truck tyres and the blocks in question, measured in preliminary experiments, were between 0.36 and 0.50 when dry for different degrees of tyre wear and between 0.27 and 0.40 when wet.

1.3.6 Objective
The objective of this study was to obtain data on how to cover motorways by the means proposed. Thus measuring shear strength at the adverse temperatures to which blocks are subjected in summer is the main objective. Three experimental factors were chosen --- concrete thickness, mix design of the adhesive layer, and the resistive height of concrete in the joints. To assess the effects statistically, a factorial design was applied to the experimental conditions

2. EXPERIMENTS OF SHEAR STRENGTH

2.1 Design of experiments
The experimental levels for the factors are shown in Table 1. The experimental results of shear strength are measured between the rubber piece and concrete according to the factorial design, shown in Table 2. The factors are illustrated in Fig.3.

Table 1. Experimental factors and levels.

Factor Level	1	2	3
A concrete thickness (cm)	1	2	3
B asphalt content (%)	8	12	18
C joint height (mm)	0	5	10

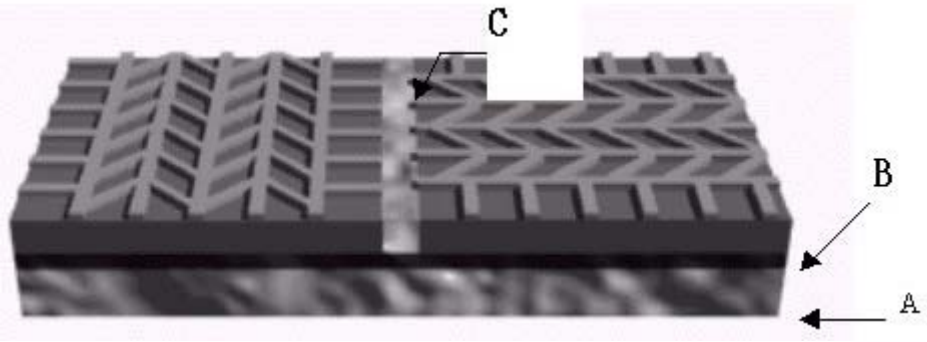

Figure 3. Test piece and experimental factors.

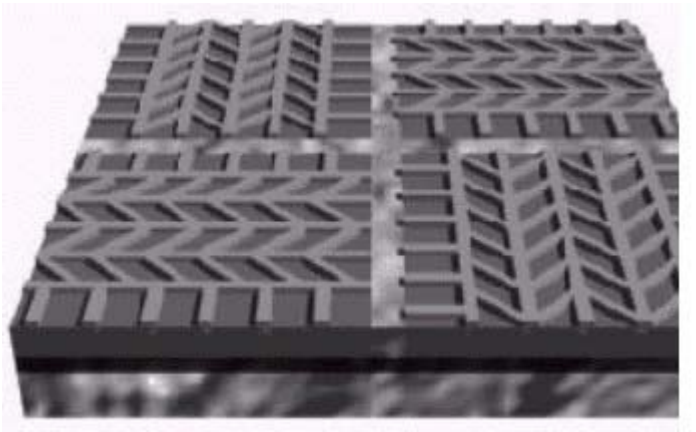

Figure 4. Rubber pieces on concrete.

2.2 Specimens

2.2.1 Rubber piece

Rubber pieces were configured as shown in Fig. 4, each piece being divided into halves for the shear test, as shown in Fig.3. The square rubber planes were prepared by cutting pieces from a rectangular plate, 100 ±5mm in width. The tyre's sidewalls are removed, leaving the tread. Each rubber piece is a quasi-square that varied in thickness from 10 to 30 mm. The steel mesh remains in the rubber piece so that the apparent coefficient of thermal expansion is smaller than that of solid rubber. After cutting the rubber pieces from normal lorry tyres, their coefficients of friction were measured and found to be between 0.38 and 0.50 when dry and 0.28 and 0.39 when wet. The same kind of rubber piece but rectangular in shape (100 mm x 1800 mm) reduced the wet coefficients to 0.23. The joints remove excess water on the surface of the piece, which raises the coefficients.

2.2.2 Preparation of Adhesive Layer

The asphalt mixture will adhere to the rubber piece when heated, as shown in Fig.5. The proportions of the mixed ingredients are given in Table 2.

2.2.3 Manufacturing procedure

Four pieces of rubber are arranged in the bottom of the form, with the tread facing down. Next comes the adhesive layer. Concrete is poured directly on top of this layer and cured for two weeks. A cross section is shown in Fig. 6. In spite of the differing thickness of the rubber, the manufactured pieces are approximately equal in size. The levels of the joint heights are adjusted by inserting a spacer shaped like a small square pillow, as shown in Fig.6. The joint part is projected from the concrete body of a block.



Figure 5. Adhesive layer and rubber piece.

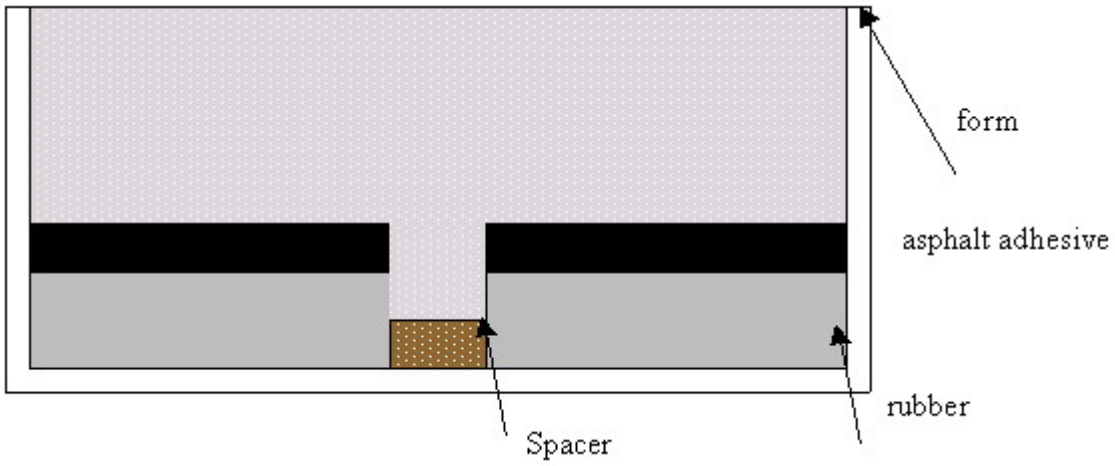

Figure 6. Cross section of test piece.

2.3 Experimental procedures

To simulate mid-summer temperatures, a test piece of concrete and rubber is preheated to 70°C. To estimate the shear force (due to traffic), the blocks are fixed in a test frame, which is then subjected to a tensile test. The rubber piece and the concrete part are held separately in two steel frames. The tensile strengths are measured when the two frames make a fracture plane. Because the same set of frames is used, the other test conditions are similar. The apparent shear strength is the tensile force divided by the area of the assumed fracture plane.

2.4 Experimental results of shear strength

The data on shear strengths are shown in Table 2. The experimental conditions correspond to the factorial design shown in Table 1. The power of interwoven effects can be statistically assessed between factors (Taguchi, 1961).

Table 2. Experimental conditions and results.

	A	B	C	Data(Mpa)
1	1	8	0	0.45
2	1	8	5	0.55
3	1	8	10	0.75
4	1	12	0	0.02
5	1	12	5	0.15
6	1	12	10	0.65
7	1	18	0	0.02
8	1	18	5	0.55
9	1	18	10	0.3
10	2	8	0	0.5
11	2	8	5	0.8
12	2	8	10	0.9
13	2	12	0	0.25
14	2	12	5	0.55
15	2	12	10	0.5
16	2	18	0	0.3
17	2	18	5	0.3
18	2	18	10	0.55
19	3	8	0	1.75
20	3	8	5	2.05
21	3	8	10	2.1
22	3	12	0	0.6
23	3	12	5	0.7
24	3	12	10	0.7
25	3	18	0	0.3
26	3	18	5	0.55
27	3	18	10	0.65

3. DISCUSSIONS

The objective shear strength is the key metric upon which the connection between the rubber piece and the concrete depends. The contribution analysis was carried out for the mean squares to find the F values and the contributions of experimented factors. From the F table, three independent factors satisfied the 1 % risk rate with statistical significance. The relationship between the three factor levels and the obtained shear strengths are shown in Figures 7 to 9.

Because the effect of the interwoven actions on the shear strengths were shown to be insignificant, the necessary shear strength may be assessed for the given conditions by these relationships. Under the assumed conditions, the asphalt adhesive proved to be capable of stabilizing the rubber pieces on the roads. If one assumes that the contact pressure of a tyre is 1.0MPa and the friction coefficient is 0.5, a shear strength over 0.5 MPa may be satisfactory.

4. CONCLUSIONS

4.1 Concrete Thickness

The concrete thickness controls the shear strength for two reasons:

- a thicker layer of concrete on top of the asphalt layer tends to show a higher specific density due to the effective compaction; and

- a thinner bed of concrete tends to buckle during the shear test and rubber separation can start at the buckling crack. This function to keep the surface material in position will increase the height. On the other hand, the thickness ought to be minimized if the height can be constant.

4.2 Asphalt Content

In this test at high temperatures, the less asphalt used the greater the shear strength of the adhesive. On the other hand, in preliminary tests it was verified that under successive freeze-thaw cycles the durability of the bond between the adhesive and the rubber pieces decreased as the asphalt content decreased. The optimum asphalt content should be based on the two conditions.

4.3 Joint Height

Concrete in the joints will work when the rubber pieces are subjected to horizontal forces. The rubber pieces, however, will be worn down ultimately. Information on the relationship between the level of traffic and wear remains to be obtained. It was observed that the traffic noise level falls considerably when the amount of concrete in the joints is reduced. Thus the replacement cost and the noise level allowable should probably be taken into account in the actual design.

4.4 Joint and Tread Pattern

The inclusion of joints and tread patterns will increase the coefficients of friction--not only by making a road surface uneven but by draining surface water.

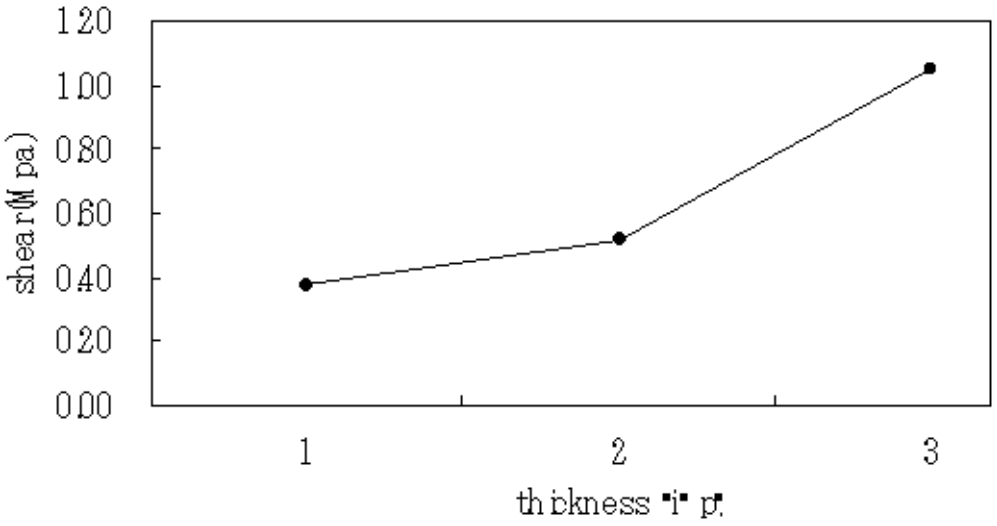

Figure 8. Effect of concrete thickness.

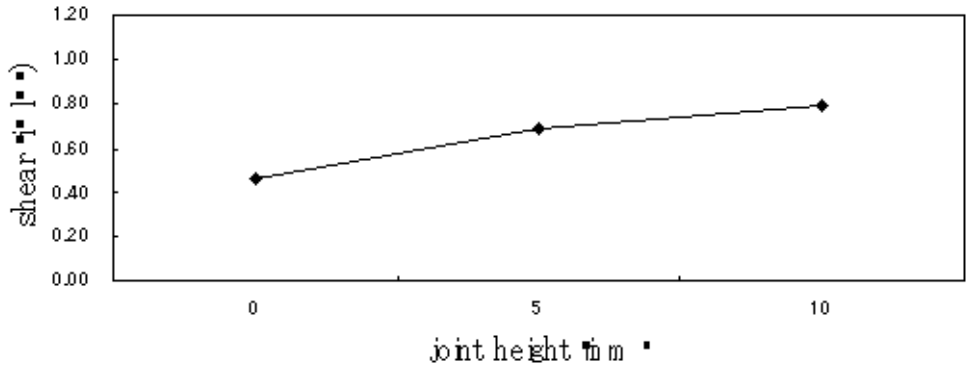

Figure 9. Effect of joint height.

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