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Tyre Bead Unseating Test

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The repeatability of the tyre bead unseating test as well as the factors affecting the bead unseating force values were investigated. The test repeatability was found to be about 2%.

The tyre bead unseating force increases linearly with the tyre inflation pressure. A simple theory is proposed which explains this observation in terms of volume change of the air contained in the tyre during the test and the area of influence of the bead unseating block. Lubrication of the bead-rim interface with silicone oil did not alter the bead unseating force. This force was also found to be independent of the speed of travel of the bead unseating block in the range of 20 mm to 200 mm per minute.

The beads of a tyre are composed of a number of turns of a high tensile, hard drawn steel wire and form a major component of the tyre. The forces that are imposed on the beads are directly related to its two primary functions of providing a rigid support over which the layers of tyre fabric can be turned around and acting as an inextensible support for rim inter locking.

When a tyre is inflated, tensile forces are developed in the fabric cords of the tyre which are resisted by the tension set up in the steel wire bead. This results in the material which encases the bead steel wire coils to be pressed against the rim flange.

In a large proportion of passenger car tyres, security of the attachment of the tyre to the rim, usually a one-piece type, is augmented by an interference fit between the tyre bead base and the rim. This results in a compressive force on the material under the bead. The magnitude of the force depends on the tyre-to-rim interference. The bases for selection of this interference fit are torque transmission, lateral trust and the sealing required for air retention of tubeless tyres. To prevent the tyre from slipping on the rim, the moment of the frictional forces at the rim has to be larger than the maximum torque transmitted to the tyre.

During the cornering of a vehicle, the tread centre in contact with the road is displaced away from the rim centreline. The extent of the displacement depends on the speed and weight of the vehicle, radius of curvature of the bend, tyre characteristics and inflation pressure. If the beads are too large or the tension developed in the beads due to inflation pressure is insufficient, the lateral centrifugal forces may exceed the forces keeping the bead on the rim resulting in the bead becoming unseated. For tubeless tyres, this results in rapid deflation of the tyre.

A measure of the bead unseating force is thus important and there is standard laboratory test equipment designed to do this. This test is intended primarily for all new passenger car tyres that do not have separate removable tubes. New low-profile wide tyres of the tubed type can also be tested[1–5].

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MATERIALS AND EXPERIMENTAL

Tyres made at the Institute were used in this investigation and were of the 6.50 – 13 (4PR) cross-ply type.

The bead regions of the test tyre are washed, dried and mounted onto the test rim without using any lubricant or adhesive. The tyre is then inflated to its test inflation pressure and allowed to stand at ambient temperature for at least 3 hours. After this required period of conditioning, the inflation pressure is then readjusted if necessary and finally the tyre-rim assembly is mounted onto the test machine as shown in *Figure 1.*

The curved block of aluminium alloy casting is pressed against the tyre sidewall at a fixed position *A* at a rate of 50 ± 2 mm per minute. Load is applied to the block until the bead becomes unseated from the rim or a specified value is reached. The force at which the bead is unseated is called the bead unseating value of the tyre-rim assembly. The test is performed at four equidistant places on the tyre sidewall.

The energy required to unseat the bead is sometimes also calculated and this is obtained from the area under the force deflection curve. Due to the rather non-linear shape of this curve, the trapezoidal

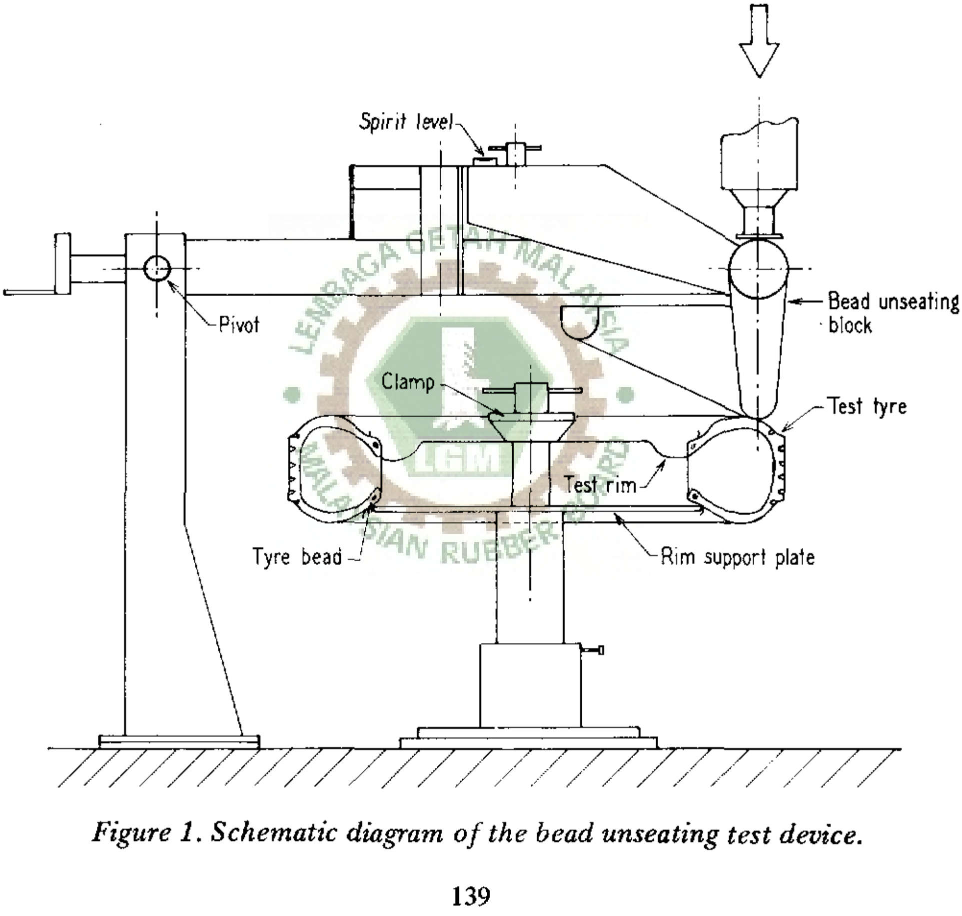

Figure 1. Schematic diagram of the bead unseating test device.

rule is used in the calculation of the area and hence the energy.

To determine the repeatability of this test, a 6.50 – 13 4PR cross-ply tyre inflated to 1.69 kg cm^{-2} was used. The tyre sidewall was divided into eight equal sections along its circumference. To reduce short-term memory effects due to previous deformation (if present) of the tyre, the eight sections were tested in the order 1, 5, 3, 7, 2, 6, 4, and finally 8. This sequence was chosen so that the next point tested was furthest away from the previous point tested on the tyre sidewall. Measurements were done on both sides of the tyre.

Volume changes of the air contained in the tyre during the test were measured using a mercury manometer connected to the valve of the test tyre with an initial apparent inflation pressure of zero. The ascent of the mercury column when the bead unseating block descends onto the tyre sidewall allows the increase in pressure and hence the reduction in volume of the contained air to be calculated.

For the investigation of the effect of tyre inflation pressure on the bead unseating force, the same tyre was used and the apparent inflation pressure was varied from 0.49 kgf – cm^{-2} to 2.53 kgf – cm^{-2}. For each pressure reading, the bead unseating test was carried out on four different sections of the tyre sidewall and the average recorded. In another set of measurements using the same tyre, the increase in the air pressure of the tyre during the test was determined by attaching a pressure gauge to the tyre valve during the test.

The effect of lubrication on the tyre bead unseating force was investigated for a range of inflation pressures using another similarly constructed experimental tyre. The bead unseating force was first measured with the rim and bead region dry and then with both the rim and bead region lubricated with silicone oil.

To determine the effect of the speed of the bead unseating block on the tyre bead unseating force, the speed of the block was increased from 17 mm to 190 mm per minute and the unseating force was measured. The inflation pressure used was 1.69 kgf – cm^{-2}.

The bead unseating force of a commercial radial tyre of the same bead diameter was tested and its value compared with that of the cross-ply tyre.

RESULTS AND DISCUSSION

Repeatability of the bead unseating test

The results of the repeatability measurements are summarised in *Table 1.*

TABLE 1. BEAD UNSEATING VALUES OF A 6.50 – 13 (4PR) CROSS-PLY TYRE[a]

Parameter	Side 1	Side 2
Sidewall displacement, L (cm)	13.1 ± 0.1	13.1 ± 0.1
Bead unseating resistance force, F (kgf)	1 200 ± 30	1 200 ± 20
Energy to unseat bead, E (kgf-cm)	7 000 ± 120	7 030 ± 180

[a]At 1.69 kgf-cm^{-2} inflation

It is clearly evident from *Table 1,* that for the same tyre, the values of tyre displacement, the force and energy to unseat the bead do not differ when changing from one side of the tyre to another if the tyre is uniformly constructed and cured. The limits given in *Table 1* are for the 95% confidence level. The repeatability of the test, expressed as a percentage of the 95% confidence limits over the mean are 0.5%, 2% and 2% respectively for the sidewall deflection, bead unseating resistance force and the energy required to unseat the bead.

Volume Changes of Air in the Tyre During the Test

If we assume that the air contained in the tyre is ideal and that no temperature change occurs in it during the test, then,

$$(P_o + P_a)\ V_o = (P_1 + P_a)\ V_1 \qquad \dots 1$$

where P_o is the apparent inflation pressure *i.e.* relative to atmospheric

P_a is the atmospheric pressure taken as 1.03 kgf-cm^{-2}

P_1 is the maximum inflation pressure at the moment of bead unseating

V_o is the initial volume of the air in the undeformed tyre

V_1 is the volume of the contained air at the moment of bead unseating

The observed maximum difference in the mercury levels in the arms of the manometer was 13.1 cm when the apparent inflation pressure P_o was zero. Applying this value to *Equation 1,* the fractional volume reduction (V_1/V_o) was found to be 0.85. This means that the volume of air contained in the tyre is reduced by 15% during the test. It will be shown later that this volume reduction is independent of the apparent inflation pressure, P_o.

Pressure Changes of Air in the Tyre During the Test

A graph of $(P_1 + P_a)$ was plotted against $(P_o + P_a)$ and is shown in *Figure 2* where P_a, P_1 and P_o are the atmospheric pressure, the maximum pressure observed at the moment of bead unseating and the apparent inflation pressure respectively. Regression of the data on *Figure 2* gave the slope of the line as 1.17. The reciprocal of this slope is 0.85. From *Equation 1,*

$$\frac{P_o + P_a}{P_1 + P_a} = \frac{V_1}{V_o}$$

hence (V_1/V_o) equals 0.85. This means that the 15% volume reduction of the air contained in the tyre during the test is independent of tyre inflation pressure.

Effect of Inflation Pressure on the Bead Unseating Force

Figure 3 shows the dependence of the bead unseating force on the tyre inflation pressure. It is clear that a linear relationship exists between the bead unseating force and the inflation pressure. Regression of the data obtained shows that this line can be represented by the equation,

$$F = 612\,P_o + 184 \qquad \dots 2$$

where F is in kilogramme force and P_o in kilogramme force per square centimetre. This means that the bead unseating force increases by 612 kgf for every increase of 1.0 kgf-cm^{-2} in the apparent inflation pressure, P_o. For the test tyre,

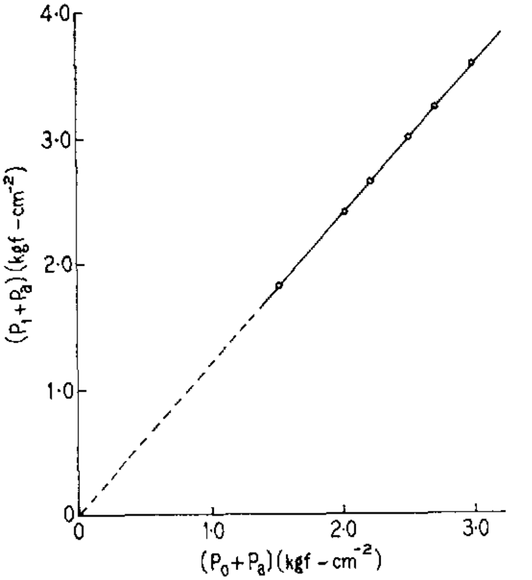

Figure 2. Pressure of contained air of tyre at point of bead unseating versus *tyre inflation pressure.*

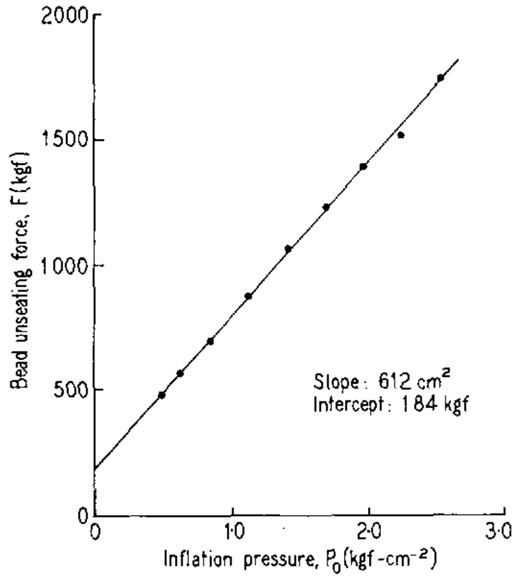

Figure 3. Effect of tyre inflation pressure on bead unseating force.

i.e. the 6.50 – 13 (4PR) tyre, the standard test pressure was 1.69 kgf-cm^{-2} and the bead unseating force was 1200 kgf. Thus, if there is an error of 0.1 kgf-cm^{-2} in the inflation pressure, the corresponding error in F will be 60 kgf which is 5% of the average value of F obtained. If it is desired to keep the error of measurement to within ± 3%, then the inflation pressure has to be kept to a tolerance of within ± 0.06 kgf-cm^{-2}.

The intercept on the y-axis in *Figure 3* is 184 kgf and this corresponds to the force required to unseat the bead when the apparent inflation pressure is zero or when the tyre is not inflated. The intercept at 184 kgf appeared to be rather large at first sight. To check this, the test tyre was inflated to 1.69 kgf-cm^{-2} to seat the bead firmly on the rim and the contained air was then released by removing the valve core. When the pressure inside the tyre equalled the atmospheric pressure, *i.e.* $P_0 = 0$, the valve core was reinserted and the bead unseating force determined. The value of F so obtained was 178 kgf which compares favourably with the value of 184 kgf obtained from *Figure 3.*

When the curved aluminium block is pushed onto the tyre sidewall, it deforms the tyre and at the same time reduces the volume of air inside the tyre. If this air in the tyre is allowed to communicate freely with air in the atmosphere as will be the case if the valve core is removed, then air is pushed out as the tyre deforms. The force that is required to dislodge the bead from the rim in this case thus represents the minimum force F_0 needed to unseat the tyre. The magnitude of this force was found to be 83 kgf for this tyre.

With the valve core in place, the reduction in volume when the block descends causes an increase in the tyre internal pressure. The block therefore needs to overcome F_o as well as an additional force which is governed by the pressure inside the tyre at the moment of bead unseating.

We shall assume that the total bead unseating force F can be represented by the equation,

$$F = F_o + F_1 \qquad \ldots 3$$

where F_o is the minimum force required to unseat the tyre bead whose magnitude depends only on the interference fit between the bead and the rim and also the frictional properties of the rubber below the bead.

F_1 is the force arising due to the tyre inflation pressure.

It has been shown earlier that

$$\frac{P_1 + P_a}{P_o + P_a} = \frac{V_o}{V_1} = k, \text{ which is independent of } P_o$$

Therefore, P_1 is given by

$$P_1 = kP_o + P_a\,(1 - k) \qquad \ldots 4$$

and can be calculated since all the quantities in *Equation 4* are known. *Table 2* shows the values of P_o, P_1, F and a quantity $(F - F_o)/P_1$ which has units of area. The values of F_o, P_a and k were taken as 83 kgf, 1.03 kgf-cm^{-2} and 1.17 respectively. The k value of 1.17 is justified since the same tyre was used in this experiment as in the previous experiment where k was found to be 1.17.

The quantity $(F\text{-}F_o)/P_1$ is constant for the range of P_o used in the experiment. We shall denote this quantity by A and call it the 'area of influence' of the bead unseating block. The value of A obtained from *Table 2* is (530 ± 8) square centimetres. It is noteworthy that at the point of unseating, the tyre deflection is constant at 13 cm and is independent of the inflation pressure.

TABLE 2. CALCULATED VALUES OF P_1 AND $(F\text{-}F_o)/P_1$ AT VARIOUS VALUES OF P_o

P_o (kgf-cm^{-2})	F (kgf)	P_1 (kgf-cm^{-2})	$(F\text{-}F_o)/P_1$ (cm^2)
0.49	491	0.75	544
0.63	562	0.91	526
0.84	689	1.16	522
1.12	874	1.48	534
1.41	1 060	1.82	537
1.69	1 232	2.15	534
1.97	1 393	2.48	528
2.25	1 521	2.81	512
2.53	1 750	3.13	533

To check the 'area of influence' of the bead unseating block experimentally, the test tyre was inflated to 1.69 kgf-cm^{-2} and the area subtended by the block and the bead as shown in *Figure 4* was measured. This area was found to be about 550 cm^2 which compares favourably with the value of A obtained.

$$\text{Writing } (F - F_o) = AP_1 \qquad \ldots 5$$

and from *Equations 4* and *5* we get,

$$F = AkP_o + A(k - 1)\,P_a + F_o \qquad \ldots 6$$

Equation 6 represents a straight line of slope Ak and intercept $[A(k\text{-}1)P_a + F_o]$ if F is plotted against P_o. *Since the terms in the square brackets are all constants (Figure 3).*

To check the magnitude of the slope and the intercept, substituting A = 530 cm^2, K = 1.17, P_a = 1.03 kgf-cm^{-2} and F_o = 83 kgf,

$$Ak = 620 \text{ cm}^2$$

$$A\,(k - 1)\,P_a + F_o = 176 \text{ kgf}$$

The above values agree very well with the values given in *Equation 2*.

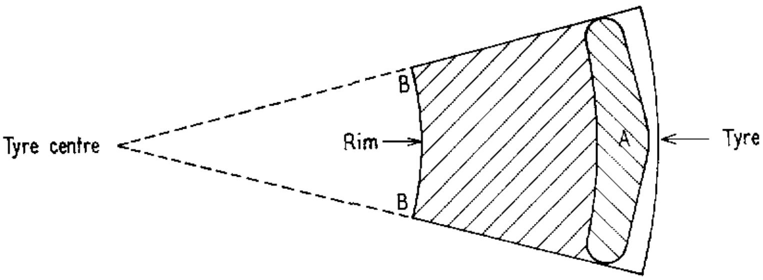

*Figure 4. Area of influence of the bead unseating block on the tyre sidewall during the test (*A *is the area of physical contact of the block on the tyre and* B *the region where the bead becomes displaced from the rim flange).*

Effect of Lubrication on the Bead Unseating Test

The results obtained for this experiment with another tyre are plotted in *Figure 5.* Referring to *Equation 6,* for the dry rim and bead contact,

$$Ak = 625$$
$$A(k-1)(P_a) + F_o = 240$$

and for the silicone oil lubricated case,

$$Ak = 635$$
$$A(k-1)\,P_a + F_o = 220$$

F_o was measured to be 75 kgf and 70 kgf for the dry and lubricated case respectively. From these known quantities, we get

k = 1.34; A = 470 cm² for the dry contact and
k = 1.29; A = 490 cm² for the lubricated case.

These correspond to a volume reduction of 25% and 22% for this tyre in the dry and lubricated conditions respectively and show that the effects of lubrication are negligible in the bead unseating test.

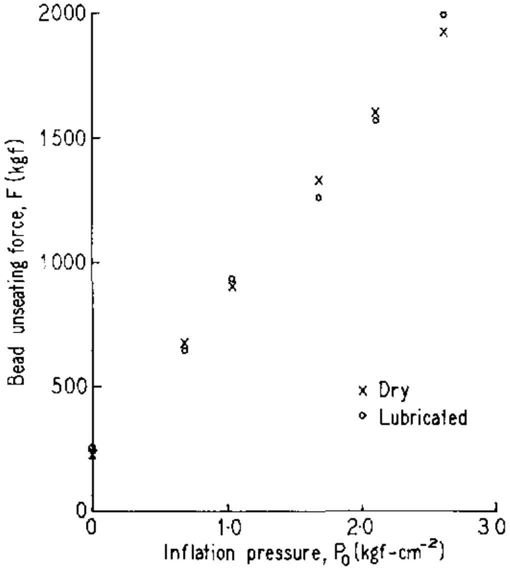

Figure 5. Effect of lubrication on bead unseating force.

Since lubrication effectively eliminates the frictional forces between the bead and rim interface, the 70 kgf bead unseating force obtained for the case of the lubricated contact at P_o = 0 and without the valve core could be attributed to the interference fit of rim and tyre used. It could therefore be concluded that the contribution of frictional forces to the total bead unseating force is indeed very small.

Effect of Speed of Bead Unseating Block on Bead Unseating Force

In the range of speed investigated, the bead unseating force, tyre sidewall deflection and the energy required to unseat the tyre beads are independent of the speed of unseating *(Table 3)*.

TABLE 3. EFFECT OF SPEED OF UNSEATING BLOCK ON TYRE BEAD UNSEATING VALUES

Speed (mm/min)	Bead unseating force (kgf)	Tyre sidewall deflection (cm)	Energy to unseat (kgf-cm)
17	1 250	12.5	6 850
50	1 250	12.6	6 870
190	1 270	12.2	6 890

Bead Unseating Values of a Radial Tyre

The bead unseating value of a commercial radial tyre was measured to compare with the experimental tyre. The radial tyre used was the 165 HR 13 4PR type and was mounted on the same test rim. At an inflation pressure of 1.69 kgf-cm^2, the values of the bead unseating force, tyre deflection and bead unseating energy were 1180 kgf, 12.6 cm and 6910 kgf-cm respectively which compare well with those in *Tables 1* and *2* for the experimental 6.50 – 13 cross-ply tyre. This is not surprising since the bead size of both tyres was identical and the same 5J rim was used.

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