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Factors Affecting the Attainment of Higher Density in Wool Bales

J. G. DOWNES*

Experiments were carried out to examine the compressibility of wool, factors affecting expansion of the bale on release from the press, and means of minimizing such changes in shape which increase the volume of the bale and reduce its density. Various means of reducing the volume of wool bales, both in shed pressing and subsequently in dumping, such as the use of concave rams or platens and mechanical constraints, are considered. It is shown that the density achieved in conventional bales is much below the max. density which existing presses are capable of producing. It appears practicable to reduce the volume of shed-pressed bales by about 25% and that of dumped bales by 35% or more.

1. Introduction

The standard Australian bale of greasy wool occupies an effective volume of 26 ft^3.[1] The effective volume is defined as that of the rectangular enclosure into which the bale just fits. The maximum overall dimensions are approximately 30 × 30 × 50 in high. Since the average gross weight is about 315 lb (the standard jute pack weighing about 11 lb) the effective density, i.e. mass/effective volume, is 12 lb/ft^3. In relation to the "deadweight cargo" density of 56 lb/ft^3, i.e. the value below which volume rather than weight is the dominant factor in determining shipping freight charges, such bales represent a load of low density.

Prior to shipment it is normal to dump, i.e. compress the individual bales in a hydraulic press and fasten steel ties around them. The shipping volume of the bale is then on the average $18\frac{1}{2}$ ft^3, corresponding to a density of 17 lb/ft^3.

Since the cost of freight is in general related to the volume occupied, it is of interest to investigate possible means of reducing the volume of bales. The potential savings on freight costs for internal transport and for shipment overseas could be substantial.

2. Attainment of higher densities in shed-pressed bales

2.1. *Compressibility of wool*

Although numerous studies of the compressibility of wool have been reported,[2, 3] in nearly all cases they have not been concerned with the aspect of denser packaging, and the values of density examined are below the range of interest in this regard. Other workers[4, 5] studied the pressure *v.* density relationship in the high-density region relevant to the dumping operation. In order to study the intermediate range appropriate to shed-pressing, i.e. pressing in the woolshed at the time of shearing, a series of compression tests was made in a $2\frac{1}{4}$ in dia Teflon-lined cylinder, using about 100 g of wool and in a metal box of $8\frac{5}{8}$ in square cross-section, using about 10 lb of wool.

Compressibility is taken to be defined by the pressure *v.* density relationship for wool pressed unidirectionally in a rigid container.

The compressibility has been considered to depend on a number of characteristics of the wool:—

- (i) the conformation or orientation of the fibres which depends in turn on the breed and age of the sheep and on the part of the body from which they derive;
- (ii) fineness (fibre diameter);
- (iii) fibre length;
- (iv) moisture content;
- (v) percentage of clean wool present (i.e. yield).

The resistance to compression of greasy wool is provided essentially by the fibre component and not the wool wax, dirt and other impurities, which are easily accommodated in the inter-fibre space except at very high densities.[4] Hence the yield, or mass of fibre present per unit weight of greasy wool, directly affects the compressibility. Indeed, methods have been investigated[3, 6] for determining yield from compression tests.

* Division of Textile Physics, CSIRO Wool Research Laboratories, Ryde, Sydney, Australia

The experimental results in the present study refer for the most part to Australian Merino fleece wool of 64's quality, average diameter about 22 μ and yield 60 %. However, they should be applicable with good accuracy to wool of different yield value provided the appropriate adjustment is made. Experiments have shown[4] that such a relationship can be validly extended to the case of scoured wool (yield 95–99 %).

In the tests the pressure was reversed at 50 lb/in^2 and a recovery curve obtained (*Fig. 1*). Times occupied in compression and recovery were about 6 and 45 min, respectively.

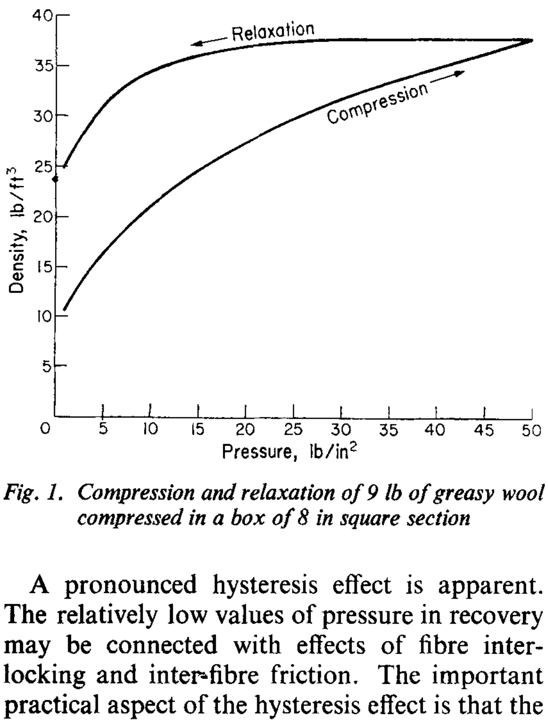

Fig. 1. Compression and relaxation of 9 lb of greasy wool compressed in a box of 8 in square section

A pronounced hysteresis effect is apparent. The relatively low values of pressure in recovery may be connected with effects of fibre interlocking and inter-fibre friction. The important practical aspect of the hysteresis effect is that the material can be held compressed by ties with values of tension much lower than the force required for compression, unlike the case of a purely elastic material.

An interesting aspect of the compression curve is that a density of 25 lb/ft^3 is obtained at a pressure of 15 lb/in^2, which corresponds to what is commonly regarded as the safe load rating of a typical woolshed press, i.e. a load of 5 tons on a ram about 28 in square. Therefore it appears that the typical shed press should be capable of compressing wool to a density about twice the effective value for the average shed-pressed bales, and indeed to about 50 % greater density than that effectively achieved in bales after dumping.

2.2. *Loss of effective density*

It is desirable to understand what are the technical causes which prevent, or render difficult, the production of bales of considerably higher density in practice.

Investigations show two main reasons:—

(a) Shed presses are commonly not operated up to the maximum safe load. Since the majority of presses are manually operated, speed of working seems to be favoured at the expense of mechanical advantage, so that the operator does not develop the maximum safe load.

(b) Expansion of the bale occurs when it is released from the press:—

   (i) There is a small lateral expansion which is self-limiting at a definite value without external constraint. The expansion is equal in the two lateral dimensions so that there is a change of area but not of shape. The linear expansion is about 7 % for most bales produced.

   (ii) There is an expansion in the longitudinal direction which would proceed indefinitely unless constrained. Such constraint is normally provided by the woolpack. Despite the pronounced hysteresis in the density *v.* pressure relationship the wool nevertheless exerts a residual pressure of the order of 1 lb/in^2 which causes the non-rigid ends of the jute pack to adopt the familiar domed shape. The resultant longitudinal expansion at each end is about 7 in.

2.3. *Means of reducing loss of effective density*

To investigate what procedures would be necessary to avoid or reduce these effects, an experimental bale was prepared. To minimize longitudinal expansion, rigid ends were provided; these were made of square pieces of sheet steel, turned down 1 in at the edges and stiffened with hardwood battens. The aim was to make an increase in the density of the bale by reducing its volume since the alternative approach of increasing the weight of a bale of present conventional volume could lead to difficulties in handling during transport and storage. The volume of the box was reduced in the cross-section rather than the height. For a given thrust in the press this permits a higher pressure to be applied, but on the other hand the proportion of the thrust lost in friction at the walls is increased.

The internal dimensions of the box of a conventional shed press were reduced to 24 × 24 in cross-section. 300 lb of greasy wool was compressed between the rigid end plates to a height of 36 in. Hence the volume of compressed wool in the box was 12 ft^3 and the density 25 lb/ft^3. The end plates were secured by steel bands (*Fig. 2*) passing down the sides of the bale. On release the bale expanded in each lateral direction about 2 in and longitudinally about 1 in, the volume becoming 14·5 ft^3 and density 20·7 lb/ft^3 (net basis). The sides of the bale are self-supporting without any constraint being applied externally, just as with other fibrous materials (e.g. cotton, hay) similarly compressed; the effect is due to the fibres being pressed together in random orientation in the cross-section of the bale.

It has thus been shown possible to produce in a woolshed press bales of effective density over 70% greater than that of conventional bales. In such bales a pack is not required for constraining the wool but might be considered desirable to facilitate handling with hooks, to reduce the chance of contamination, as a safeguard against band breakage, to prevent moth attack, and as a means for labelling the bale. The disadvantages are the appreciable cost of providing rigid ends and the difficulty of opening the package to permit closer examination and appraisal, e.g. at auction sales, and closing it again.

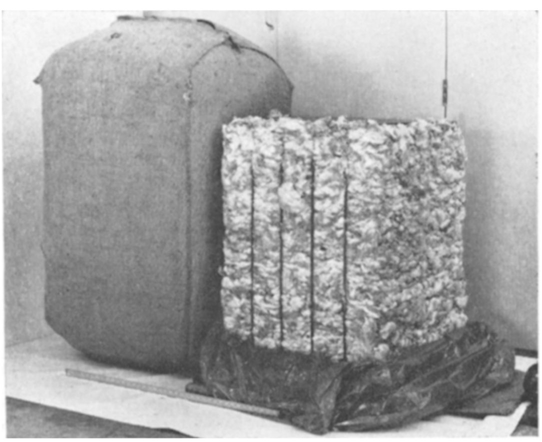

Fig. 2. Conventional bale (left) and shed-pressed bale with rigid ends and without pack

An alternative approach to reducing the loss in density from longitudinal expansion is to arrange the press so that the ends of the bale adopt the characteristic dome shape produced in the pack under the residual pressure exerted by the wool after release. The ends would then become filled with wool at the same high density as throughout the bale and no further change of shape can take place on release from the press. A bale prepared in this way will have a density 18% higher than one pressed in a box having the conventional flat bottom and platen, the pressing thrust and overall dimensions on release being the same.

In practice development of a dome-shaped end during pressing is easy to achieve at the bottom of the bale, but less easy at the top where the ram is present and closure of the bale is carried out.

On an experimental basis a number of bales have been pressed in jute packs using rams with flat or concave faces. To achieve high density in the press box without increase in bale weight, the cross-sectional dimensions of the box of a conventional shed press were reduced, as before, to 24 × 24 in. A standard jute pack, having 28 in sides, was used. The pack was so positioned in the box that at the bottom of the pack the dome-shaped end was formed during pressing. At the top end the conventional pressing and closing methods were followed, using a flat monkey.

As an example, 6 bales were pressed having net weights in the range 299–310 lb. The overall dimensions of the bales were 26 × 26 × 46·2 in high (average), i.e. the average volume was 18·1 ft^3 and average density 16·7 lb/ft^3. This volume is 30% below that of the average conventional bale. A consequence of a reduction in lateral dimensions is that the effective volume taken up by the bulges at the bale ends is reduced (roughly in proportion to the cube of the relative reduction in a lateral dimension) and the effective density of the bale as a whole is therefore increased.

Since the final dimensions of the wool in cross-section are only 26 × 26 in, while the side of the pack is 28 in, the pack is not providing any constraint around the girth of the bale. The sides of the pack are serving only to hold the ends in position. The sides of the bale are flat and the side corners rectangular, similar to the bale of *Fig. 2*, and for the same reasons; the bales can therefore be assembled in stacks of good stability (*Fig. 3*), thus offering considerable savings in storage space.

Fig. 3. A stack of "slack-pack" bales in a wool store

In contrast, the conventional bale is somewhat rounded in cross-section. The reason is that the side measurement of the pack is equal to that of the press box (28 in) and on release from the press the lateral expansion (about 7%) of the wool cannot be restrained by the non-rigid pack except at the corners, where the radius of curvature is small.

A substantially greater number of bales can be carried safely by road and rail vehicles; for example, a road truck normally carrying a maximum of 42 bales safely carried a load of 58 "slack pack" bales and a rail truck 72 instead of 61 conventional bales.

2.4. *Effect of friction in wool pressing*

When wool is compressed into a container, frictional forces arise as a result of the lateral pressure on the walls. These forces produce undesirable effects:—

(i) when pressing into a jute pack the friction develops considerable tension in the pack and may cause it to tear;

(ii) friction opposes the compressive thrust so that the latter is effectively reduced, with a corresponding reduction in density. The effect is greatest in the vicinity of the walls, because of the low shear strength of bulk wool and hence its limited ability to transmit into the interior of the bulk a frictional force acting along the surface. It is likely that in outer regions near the bottom of the bale the pressure is small compared with that in the vicinity of the ram.

An examination of the nature and magnitude of the frictional effects is, however, beyond the scope of the present paper, and unless stated otherwise these effects will not be considered here.

2.5. *Stresses in the pack material*

In the production of shed-pressed bales the greatest stress to which the pack is subjected arises from the frictional drag by the wool on the jute pack during the pressing operation. If at the top of the press box the pack is gripped evenly around its entire girth then it is unlikely to be torn during pressing. If the entire thrust of the press were opposed by friction, an extreme case never encountered in practice, and the thrust is assumed to be 5 tons, this represents a stress on the pack (side measurement 28 in) in the longitudinal direction of $\frac{5 \times 2240}{28 \times 4} = 100$ lb/in width of pack material, which is somewhat below the tearing strength of typical pack fabric (125 lb/in in the warp direction, which coincides with the longitudinal direction of the pack). If, however, the pack is held at the top of the press box only at a number of points (e.g. on pins) or at sharp edges, then there is a danger of tearing occurring during pressing.

When the bale is closed after pressing by fastening together the flaps at the upper end, the residual pressure exerted by the wool is resisted by tension developed in the pack material. Assuming a residual pressure in the wool of 5 lb/in^2 (an extreme value unlikely to be reached in practice) the force over an area of 784 in^2 (i.e. 28 × 28 in) is 3920 lb or 35 lb/in width of fabric in the sides of the pack. This stress is easily resisted by the material of the average jute pack; it may, however, be expected to produce a longitudinal extension of about 4%, i.e. 1½ in in the 36 in lengthwise dimensions of the pack side.

2.6. *Lateral pressures developed during pressing*

Some studies have been made of the lateral pressure developed when wool is compressed longitudinally in a rigid box. The measurements have been made in a conventional wool press over the range of density likely to be encountered in practice, and in small-scale experiments (using 10 lb of wool) at much higher values of density. The tests were made

(i) to determine whether attempts to increase the density of shed-pressed bales might be affected by the ability of the press to withstand the lateral forces developed, and

(ii) as part of an analysis of the effect of frictional forces which act at the sides of the press and may reduce substantially the thrust available for compression.

The lateral pressure was found to be (*Fig. 4*) about one-quarter of the longitudinal pressure and at the higher densities is rising somewhat less sharply than the latter. For a bale of wool of average yield, e.g. 60%, and gross weight 500 lb, which is not likely to be exceeded in the shed-pressing operation, the density in the press box, assumed to be 28 in square by 36 in deep, is 30 lb/ft^3 and the lateral pressure 9·4 lb/in^2, which should be within the capacity of the typical shed press. This pressure represents a thrust on each side of the press box of 4·2 tons.

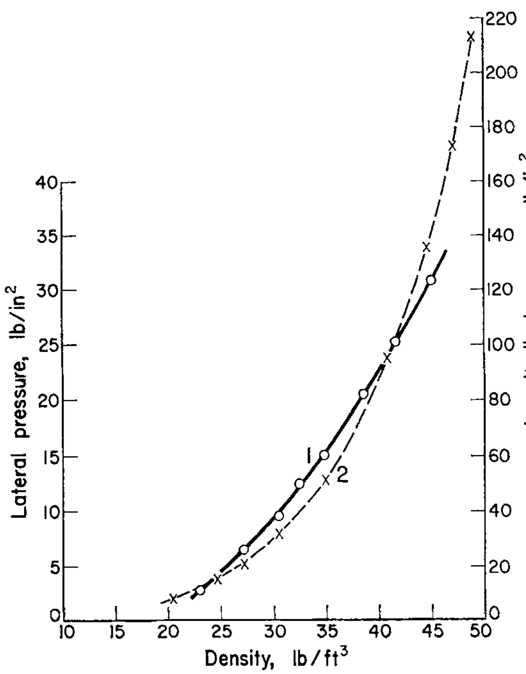

Fig. 4. Lateral (1) and longitudinal pressure (2) in relation to density for greasy wool

2.7. *The mechanism of lateral expansion*

The slower rate of rise of lateral relative to longitudinal pressure with increasing density is thought to be associated with a decreased tendency to lateral expansion as the fibres become constrained to lie more nearly in planes normal to the direction of compression. It is suggested that the component of fibre length in the direction of compression is responsible, by a buckling or bending action, for lateral expansion. As compression proceeds, the relative magnitude of this lengthwise component decreases. To consider a limiting case, in which all fibres lie in planes normal to the axis along which compression takes place (but are randomly oriented within the planes), there is no obvious reason why such an assembly should show appreciable lateral expansion.

This suggestion is supported by the result of an experiment in which 12·5 lb of greasy wool was compressed to a high density (50 lb/ft^3) in a box 9 × 9 in cross-section. The wool was held constrained at its minimum height in the direction of pressing, and the sides of the box removed. The lateral expansion was 4%, which may be compared with the value of 7% typical for expansion on release of shed-pressed bales from the press box.

In compressing bales an interesting effect related to lateral expansion has been observed. While wool was under compression in the press box, long pins were inserted into the wool through holes in the side of the box, the pins being parallel, normal to the axis of compression and widely spaced (e.g. 6½ in apart, the box side being 8⅜ in wide). On release, the increase in spacing between the pins was observed to be small in comparison with the increase in lateral dimensions of the bale as a whole (average 2 and 7% respectively). A possible explanation is that the pins are held along their length at a number of localized regions of high density where the fibres have little or no component of length in the direction of compression and thus little tendency to expansion; these and similar regions through the bales may be inter-connected to form a network whose tendency to expand is much less than that observed for the bale as a whole.

3. Attainment of higher densities in dumped bales

3.1. *Characteristics of conventional bales*

Although in respect of freight, increased shipping density appears very desirable, it has to be considered whether an increase in density will have any adverse effects on the properties of the wool.

Roberts and co-workers,[4, 7] show that up to densities of 30 lb/ft^3 adverse effects on processing behaviour are negligible; evidence from small-scale experiments suggests that considerably higher values of density could be used safely. It is normal practice for South American wool to be shipped in 1000 lb bales of density up to 30 lb/ft^3.

The maximum load applied by typical Australian hydraulic dumping presses is about 100 tons. This force acts over an area of 32 × 32 in which are the approximate dimensions to which a standard bale expands laterally on compression; the maximum pressure is therefore about 220 lb/in^2 (*Fig. 5*). The curve was obtained using a 100 g sample of wool compressed in a cylinder, precautions being taken to minimize frictional effects on the walls by using a "floating-cylinder" technique. Pronounced hysteresis is apparent in this curve also, as in that for shed-pressing. At a pressure of 220 lb/in^2 the density is 49 lb/ft^3, which is very much greater than the shipping density attained in dumped bales. This demonstrates a substantial loss of density occurs when the bale, after banding with steel ties, is released from the dumping press, due to failure to take up slackness when fastening the ties and inability, with currently used banding methods, to retain the shape of the bale on release. Despite the pronounced hysteresis, the residual force acting in the bale after release is typically in the range 2–5 tons. This force acting on the non-rigid ends of the bale causes them to assume the form of approximately cylindrical sections. In a typical case, the height of the bale under full load in the press might be 11 in (it is assumed here that the platen surfaces are flat), with lateral dimensions 32 × 32 in. Assume four bands to be fastened without slack around the bale at this stage (*Fig. 6*). On release, the top and bottom of the bale assume the curved form shown, the heights of the arcs being about 7 in each. In order for the tie to be able to take up the form of such an arc, the points on the tie originally at the edges of the bale must each be capable of being pulled in about 1·5 in. If the residual force in the bale is 2 tons, then the tension in each band will be 2 tons/8, i.e. 560 lb. Assuming a band spacing of 8 in. and a radius of curvature of the tie at the corner of the bale of 3 in, the average pressure on the bale in this region is 23 lb/in^2; at this pressure the ties will easily pull in the stipulated 1·5 in.

A bale banded without slack in the ties thus increases in height from 11 to 25 in on release.

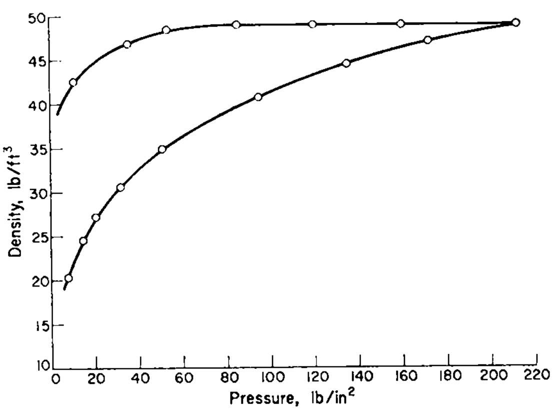

Fig. 5. Longitudinal pressure in relation to density for greasy wool

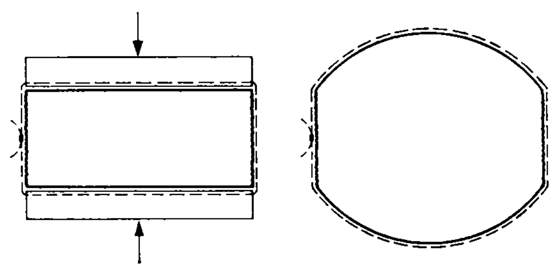

Fig. 6. Cross-section of a dumped bale (in a plane parallel to the ties) under full load (left) and on release from press

Since the lateral dimensions change little on release, the effective density is reduced approximately in the proportion 11:25, i.e. from 45 to 20 lb/ft^3. An initial value of 45 lb/ft^3, rather than the 49 lb/ft^3 quoted earlier on the basis of small-scale experiments, is used here as being closer to the effective value in that it takes account of some unevenness in the sides of the bale. Should the bands have been applied with slack then the loss of density on release will be even greater (A. McD. Richardson, private communication); e.g. an excess of 6 in band length would increase the bale height by 3 in to 28 in and the density would be approximately 17 lb/ft^3.

3.2. *Methods for obtaining increased density*

3.2.1. Application of bands without slack

Slack in ties may be avoided or reduced by use of special fastenings on the ties which permit manual closure with minimum slack, or by the use of closing tools which cause the slack to be taken up in the fastening operation. Increases of up to 20% in the effective density of conventionally dumped bales may be obtained (A. McD. Richardson, private communication).

3.2.2. Alteration in the shape of shed-pressed bales

If the shape is modified from that of the conventional shed-pressed bale in that the lateral dimensions are reduced (Section 2.3), the change has several important consequences in the behaviour of the bale during the dumping operation.

The effects of reducing the cross-sectional area are as follows:—

(a) For the same thrust the dumping pressure is increased. For the example quoted there is an increase of about 30% in the maximum dumping pressure, in that the lateral dimensions under full pressure are 28 × 28 in compared with usual values of 32 × 32 in. A 30% increase in pressure (220–286 lb/in^2 can be expected to produce a density increase from 49 to 52 lb/ft^3. At these values, the height of a bale of 300 lb of greasy wool of about 60% yield under full pressure would be 10·3 in for a standard bale and 12·7 in for a narrow bale.

(b) The dimensions of the arcs at top and bottom of the bale are smaller when the dump pressure is released after affixing the ties. The percentage change in the overall height of the bale on release and the loss of effective density are thus reduced. For example, assuming bands to be applied without slack, a standard bale would have a height in the press of 10·3 in (bulge height 7 in) and an overall height on release of 24·3 in, giving a relative increase of 136%, whereas a narrow bale under comparable conditions would have heights of 12·7 and 24·7 in respectively (relative increase 94%).

(c) In typical dumping presses the platen dimensions are such that at times there is a tendency for bales to extend beyond the platen edges. The edges of the bales are then not subjected to the maximum pressure and tend to be soft. On release of the bale from the press the ties as they come under tension are able to penetrate these soft edges rather easily causing an appreciable increase in the height of the bulge which develops. This effect is minimized in the case of the narrower bales, which lie wholly within the platen area.

It will be seen that a narrow bale of 300 lb net weight, dumped and banded without slack, might be expected to have final overall dimensions of 28 × 28 × 24·7 in, i.e. a shipping volume of 11·2 ft^3 and shipping density (allowing a pack weight of 11 lb) of 27·8 lb/ft^3. Several narrow bales have been dumped under experimental conditions and have given confirmatory results, the shipping volume lying in the range 11–12 ft^3, compared with an average of 18·4 ft^3 for the conventional Australian dumped bale.

3.2.3. Alteration of one or more lateral dimensions of the bale as part of the dumping operation

Although considerable improvement in the density of dumped bales can be obtained as a result of a reduction in the lateral dimensions of shed-pressed bales in practice no substantial change along these lines can be expected in the near future, since over 100 000 wool producers in Australia are equipped with presses to produce standard bales.

A suggested alternative has therefore been to modify the dumping process, applying a small side pressure to reduce one or more lateral dimensions of the bale just before the usual longitudinal compression. The argument in favour of this procedure is the same as for the narrow shed-pressed bale.

As an example, suppose a standard bale, having cross-sectional dimensions 30 × 30 in, to be compressed sideways in one direction and constrained from expanding in the other lateral direction so that the cross-section is changed to 30 × 20 in. A lateral thrust of about 8 tons suffices. If the usual 100-ton thrust is now applied longitudinally the pressure at the top of the bale will be 373 lb/in². However, there will be considerable frictional forces acting on the sides of the bale, so that the average pressure will be less, perhaps about 320 lb/in². The corresponding density is 53 lb/ft³. For 300 lb net weight of wool the height under full compression would therefore be 16·3 in. Assume that ties are fastened around the bale without slack and that on release from the press expansion of each lateral dimension occurs to the same extent, i.e. 7%, as has been observed in shed-pressed bales. The lateral dimensions will then be 32 × 21·5 in approximately. The lateral expansion will cause some tension to be developed in the ties, but this will affect only slightly the height of the bulges which develop at top and bottom; these bulges, if reduced in proportion to the width, would be about 5 in each. The overall height might then be 26 in and the volume of the bale 10·4 ft³.

It thus appears possible, by the use of a biaxial dumping press, but without exceeding the currently-used value of longitudinal thrust, to produce bales of volume much below that currently attained in practice.

Some small-scale experiments have been conducted to find the pressure necessary if shed-pressed bales are to be compressed laterally as a preliminary step in the dumping operation. Model bales in the weight range 7½–15 lb were used. After being formed by unidirectional compression in the usual way, they were transferred to a box closely fitting at the top, bottom and three sides of the bale and having a movable fourth side to which a measured force could be applied. *Fig. 7, left*, shows the observed relationship for a bale of initial density 15·2 lb/ft³, which is approximately the average actual density of Australian bales. For compression to two-thirds of the initial width the pressure required is 17·5 lb/in². Applied over the side area of a bale, taken as 30 × 36 in, the total thrust required is 8·5 tons, which is small in comparison with the longitudinal dumping thrust.

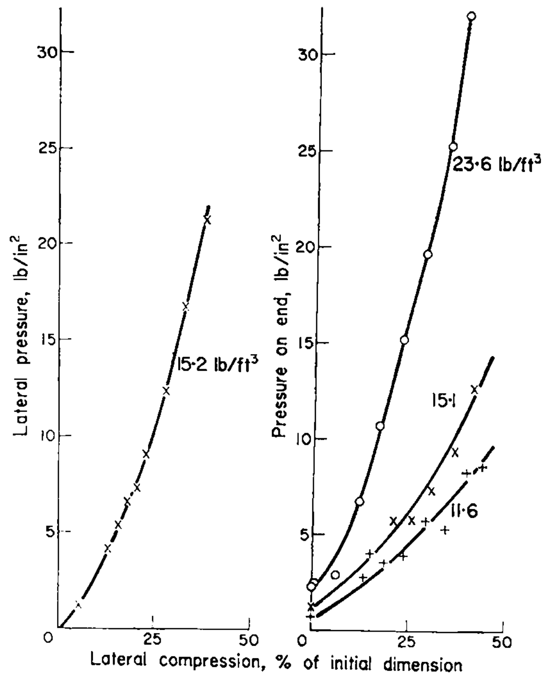

Fig. 7. Lateral compression achieved at different pressures and initial densities

Fig. 7, right, shows that for a model bale of actual density 15·1 lb/ft³ initially, compressed to two-thirds of its width, the end pressure is about 9 lb/in². Making the conservative assumption that this pressure is to be resisted by hoop tension in a surface of single curvature with radius of curve 20 in. (corresponding approximately to a bale width of 30 in and arc height of 7 in), the tension required is 180 lb/in width of fabric. This should be within the breaking strength of typical jute fabric in the weft direction (250 lb/in), although it exceeds that in the warp direction (125 lb/in).

3.2.4. Mechanical constraint of bands to prevent bulging at the bale ends

Since in the case of a resilient material such as wool, ties around the periphery of the bale are unable to resist the development of bulges at the ends of the bale on release from the press, the high density achieved during the pressing stroke is not retained. This effect could be avoided if the bale were to be fitted with rigid end plates held together by bands passing down the sides of the bale, but the probable cost of such plates capable of resisting loads of several tons make such a solution uneconomic.

An alternative method aimed at producing a similar effect appears practicable. The method is to insert links or staples through the bale at the time of dumping, joining the top and bottom of each tie together at their midpoints (*Fig. 8*). On release the bulging of the ties and hence the bale ends is substantially reduced. A number of methods appear possible for performing the stapling operation; one which has been shown feasible and relatively simple is to insert the staples with the aid of a spear which is forced through the bale in the compressed state by hydraulic rams mounted above the presses. The tie is applied and fastened in the usual way and the actions of the operator hardly differ from those in conventional dumping. A number of bales of shipping volume 13 ft^3 have been produced experimentally in this way and it is likely that this value can be reduced further. A volume of 13 ft^3 represents a reduction of 30% from the present average. Further, the dimensions of the bales produced by this method are such that 72 could be fitted inside a standard shipping container (20 × 8 × 8 ft external dimensions) as against 42 conventional bales.

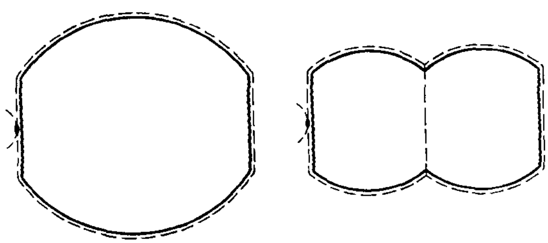

Fig. 8. Use of staples or links within the ties to reduce tendency to the formation of bulging ends

3.2.5. Use of platens of appropriate profile

The shape of the platen should conform as closely as possible to that which the bale takes up on release from the press, so that the change of shape of the bale on release of dumping pressure is minimized. This concept is closely related to that already discussed (Section 2.3) in connection with the formation of shed-pressed bales: that the bulges at the ends of the bale should be formed in the course of the pressing operation.

Using a planar platen, a bale compressed to a height of 11 in under the maximum thrust of the dumping press expands on release to an overall height of 25 in due to the development of bulges at top and bottom (arc height 7 in). Let us now consider the case, in which each platen is concave, of cylindrical section, with a maximum depth of 7 in (*Fig. 9*). Such a platen may be regarded as having an "equivalent plane" at some level within the concavity, the separation of which is by definition equal to that which would have been achieved with flat platens. On release, assuming no shape change occurs, the height of the bale is several inches less than had flat platens been used. The tension in the ties would, of course, be higher.

Most dumping presses are in fact equipped with concave platens. Such concavities have been provided to assist the locating and stabilizing of the bale prior to dumping. The profile, however, is of a rather flattened arc, considerably more shallow than required to conform to the bulge on a dumped bale and thus not very

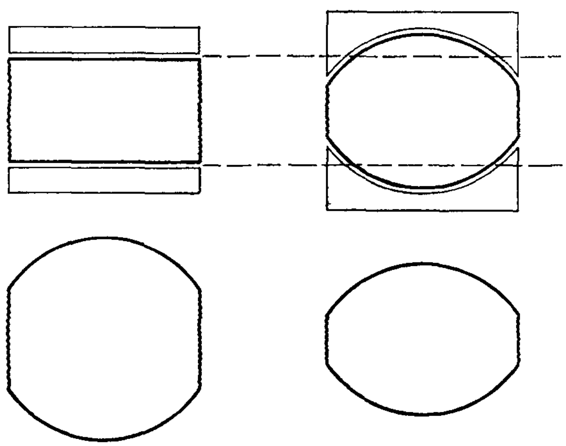

Fig. 9. Section through concave platen and equivalent plane

effective in minimizing shape change on release of pressure.

In the case of a bale, the ends of which on release tend to take up a shape other than a cylindrical bulge, the platen shape should be chosen accordingly. A particular case of interest is the bale dumped using the method described earlier in which the top and bottom of each tie are stapled together so that the ends of the bale on release are much flatter than usual. In this case use of platens which are flat rather than cylindrically concave would result in minimum shape change on release.

4. Conclusions

(a) An examination of the pressure *v.* density relationship for unidirectionally compressed wool shows that the effective density achieved in conventional bales is much below the maximum density which existing presses are capable of producing. This applies both to bales as produced in the woolshed and to those designed for transport overseas.

(b) In the case of shed-pressed bales the difference in density is due to
  - (i) a deliberate avoidance of dense bales;
  - (ii) failure to exploit fully the maximum pressure which the press construction is capable of withstanding;
  - (iii) expansion of the bale on release from the press.

(c) Methods have been investigated by which it appears practicable to produce bales at least 25% smaller in volume than conventional bales.

(d) In the case of dumped bales the difference in density is largely due to expansion of the bale on release from the press.

(e) Several methods have been developed for minimizing the expansion and it appears practicable to reduce the volume below that of conventional dumped bales by 35% or more.

(f) The potential economies which might be effected in the transport of bales, particularly in the case of dumped bales shipped overseas, are such as would appear to justify substantial investment in equipment capable of producing bales of higher density.

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