Unpublished Report

Document ID:	SheepCRC_12_27
Title:	Loose-wool feltability of individual sheep
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Key words:	wool; felt ball; fleece; characteristics; felting

This report was prepared as part of the Sheep CRC Program 2007-2014. It is not a refereed publication. If the report is quoted it should be cited as:

Sheep CRC Report 12_27

CRC for Sheep Industry Innovation

Program 2 **NEXT GENERATION WOOL QUALITY**

- Handle in Merino Wool Fabrics

Report on Loose-wool Feltability of Individual Sheep from the CRC Information Nucleus Flock

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CSIRO Material Science and Engineering

November 2009

Background

Felting is a unique property of animal keratin fibres and is considered to be the result of progressive fibre compaction and entanglement that occurs when individual keratin fibres within a loose mass, yarn or fabric are agitated in the presence of water by unidirectional external forces (Makinson, 1975, Schlink et al., 2009). In the case of wool, felting is a heritable trait (Greeff and Schlink, 2002) and this felting property allows industrial felts and non-woven fabrics to be made from loose wool and allows woollen fabrics to be milled during finishing for surface effects. However felting during raw wool scouring, wet processing of yarns and fabrics and in the laundering of finished knitted and woven wool products is highly undesirable. Consequently wool felting has been extensively studied and reported in the literature, particularly studies on how the fibre, yarn or fabric properties and the conditions of felting influence the felting process.

The basic mechanism of felting in wool is believed to be due to a directional frictional effect (D.F.E) that allows the wool fibre to move preferentially and irreversibly in the root-ward direction (Rippon, 2008, Makinson, 1975, Liu and Wang, 2007). The slightly overlapping scales on the surface of the wool fibre cause the frictional characteristics of the fibre to differ according to the direction of rubbing. For example, the wool fibre is rougher when rubbed against-the- scale (from tip to root) than when it is rubbed with-scale (from root to tip). However the presence of scales and the D.F.E does not fully explain felting. For example weathered tips, with low D.F.E, felted more than high D.F.E fibres (Zahn and Blankenburg, 1962) and samples whose scale structure was been destroyed by photochemical degradation still felted (Blankenburg, 1969). Ladyman reported that scale height contributed to significant differences in felting ability of wools with low fibre curvature (Ladyman et al., 2007).

Most studies on wool felting have been carried out on yarn or fabric. The Aachen felting test (I.W.T.O-20-69(E)) was developed to measure the feltability of loose wool, particularly greasy wool before scouring as a method of anticipating undesirable felting in scouring and for the evaluation of shrink-resist treatments on tops (Blankenburg, 1969). In this test, 1g sample of clean wool is agitated for 60 minutes forming a felted into a spherical ball. The diameter of the felt ball (FBD) is measured and used as an inverse measure of the degree of felting. Alternatively the density of the felt ball is calculated and is used as a direct measure of the degree of felting. Recently, this test was modified to enable testing of large numbers of samples more quickly. In this modified test, a tumble drier was used to agitate samples for only 30 minutes (Kenyon and Wickham, 1999).

Using the modified tumble drier method Dowling et al (2005) found that the feltball diameter of wool from a sheep varied over the lifespan of the sheep. Kenyon et al (1999) found that for ‘quarter merino’ samples the loose wool feltability was most strongly correlated with bulk, crimp frequency and lustre whilst length and diameter played only minor roles in loose wool felting. These results supported earlier findings that felting of loose wool fibre was heavily dependent on the fibre crimp characteristics and compression properties (Chaudri and Whiteley, 1968, Chaudri and Whiteley, 1970a, Chaudri and Whiteley, 1970b). Elliot and Lohrey (1982) found that bulk accounted for 62% of the variation in felting between different New Zealand wool types. Veldsman and Kritzinger (1960) found that wools with a low degree of crimp in relation to fibre diameter, particularly exemplified by under-crimped copper-deficient wools, had a much greater feltability than wools with a high crimp/diameter ratio, whilst Fraser and Pressley (1958) also showed that wool from a mutant merino where fibre were almost crimpless, felted more readily than normal wool. Schlink (2009) showed that felt ball diameter was significantly correlated with curvature, staple strength, position of break and fabric felting shrinkage, however Sumner (2009) could not find any significant relationship between felt ball diameter and any single fibre property such as crimp frequency, fibre curvature, scale dimensions and softness ranking using the modified tumble drier method. He found that variation in feltability was influenced by aspects of the cuticle profile and cortical structure associated with fibre diameter and proposed a four term prediction model using $\log_e$

transformed prediction variables for mean fibre diameter, mean fibre curvature, scale height and scale length that could explain 70% of the variation in feltball diameter.

Using a dying machine similar to a Laundrometer as a source of fibre agitation, Liu and Wang (2007) showed that alpaca fibre has a higher felting propensity than wool, whilst cashmere has a lower felting propensity than wool fibres of a similar diameter. With their technique of agitating samples for 75 minutes with steel balls, they were able to show that fibre length had a significant influence on fibre feltability, with longer fibres felting more than shorter fibres. They also found that fibres cut to 10mm in length would not felt.

The friction of dry wool is believed to contribute to tactile properties of fabric and loose wool (Makinson, 1975, Rippon, 2008) and it is feasible that the feltability of loose wool, which is partly determined by scale structure, may be related to the handle or softness of the wool fibre. Kenyon (1999) and Sumner (2009) have attempted to correlate softness or handle to felt ball diameter. Kenyon found that handle accounted for 19% of the total variation in loose wool felting, however Sumner could not find any significant relationship between felt ball diameter and softness.

The present work reports on the establishing a robust method for determining the loose wool feltability of greasy mid-side wool samples on equipment that is presently available at CSIRO (CMSE) Belmont and establish if any of the INF fibre characteristics, in particular, fibre curvature, resistance to compression, diameter, length and handle correlate with loose wool feltability.

Materials and Methods

(i) Wool sample source

Feltball method development

The following greasy wool and top sliver were used for the development of the feltball testing method at CSIRO and for the subsequent assessment of felting kinetics:

1) greasy wool (mill stock – fibre diameter 18.2µm, CVd 19.0%, curvature 111°/mm, staple length 80mm, CVh 15.6%)

2) Control wool top sliver (fibre diameter 22.4µm, CVd 21.3%, curvature 75.5°/mm, hauteur 70mm, CVh 46.1%)

3) Chlorine hercosett top sliver (fibre diameter 21.4µm, CVd 22.5%, curvature 74.7°/mm, hauteur 65.5mm, CVh 45.4%)

4) Chlorinated top sliver (fibre diameter 22.2µm, CVd 22.3%, curvature 68.2°/mm, hauteur 80.6mm, CVh 44.9%)

Feltball Characterisation of INF greasy wool samples

The mid-side samples for felting characterisation of INF wools were sourced from the 2007 Information Nucleus Merino progeny. Eight samples were selected. Pairs of samples were matched for diameter and curvature but with extremes in resistance to compression. Objective and subjective data for these samples are fully documented in the INF database (Armidale).

(ii) Sample preparation

Greasy wool

A 10g sub-sample of each greasy mid-side sample was solvent scoured for 3 hours in 180ml of dichloromethane in a Soxtherm (Gerhardt) extraction unit, then dried at 50°C overnight.

Cleaned wool samples were conditioned at 20°C and 65% relative humidity for at least 6hrs before being processed through a Shirley Analyser which randomised the fibre alignment and removed much of the residual dust, dirt and vegetable matter. Samples were then hand carded and 1g samples were preformed into balls of 5-8cm in diameter, as described in I.W.T.O-20-69(E), in preparation for felt testing. Where specified, some solvent scoured wool staples were cut in half to assess the influence of fibre length on feltability, whilst other samples were given a gentle scouring in a four bath aqueous scour using Lissapol TN450 (ICI) detergent either before or after being solvent scoured. For aqueous scouring all baths were set at 65°C and the first three baths contained 0.05% w/v, 0.05% w/v and 0.025% w/v, detergent respectively. The final bath contained water only.

Top sliver

Wool fibres pulled from top sliver did not require solvent scouring or any carding. Instead fibres were positioned randomly on a laboratory work bench and rolled to form 1g balls with diameters of 5-8cm. For fibre length studies, top sliver was either cut directly or 100mm fibres extracted from the top were cut to lengths between 10 and 100mm. Cutting the sliver resulted in the nominal length of the sample being less than or equal to the cut length whilst cutting the 100mm fibres resulted in all fibres being of equal to the nominated length. The samples were formed into 1g balls of 5-8cm in diameter in preparation for felt testing.

(iii) Loose wool feltability – method development

Given that the Aachen Felting Tester was not available for use in this trial, three alternative forms of fibre agitation were assessed with respect to developing a robust technique for felt ball assessment at CSIRO. The three methods of agitation included a domestic tumble dryer, Laundrometer and Labomat laboratory dyeing machines. Experimental conditions were varied to optimise felt ball formation for each of these forms of agitation.

The resulting felt balls were dried at 50°C and reconditioned to 20°C and 65% relative humidity. The diameter of each ball was measured in the x, y and z planes using digital callipers and the average diameter was calculated for each felt ball. Small diameter feltballs indicate greater the felting.

Tumble dryer method

A modified version of the tumble dryer method developed by Kenyon and Wickham (1999) was used where 1g wool was placed into a 250ml rectangular shaped, screw capped plastic container instead of a 75ml plastic jar. Deionised water (25-100ml) and up to 25 small (1g) stainless steel balls were also added to the container. The plastic container was then encased in cushioning material to minimise noise and damage to the clothes dryer, and samples were randomly tumbled for up to 60 minutes dryer using the warm setting.

Laundrometer method

In this method, the 1g wool balls were agitated at 40°C for up to 60 minutes with 25-100ml of deionised water and up to 25 small (1g) stainless steel balls. The Laundrometer agitation was fixed at 43 r.p.m.

Mathis Labomat method

The 1g wool balls were agitated at 30°C or 40°C for up to 180 minutes with 25-100ml of either deionised water or ph 6.8 buffer solution and up to 50 small (1g) stainless steel balls in 350ml cylindrical dyeing pots. The wool samples were completely wet out, by placing a brass weight (2.2 Kg) on top of the wool sample to ensure that the wool is submerged in the felting medium. The agitation of the Mathis Labomat was accurately set at 15 r.p.m to 60 r.p.m, with the direction of rotation reversing every 50 seconds. The pH 6.8 buffer was prepared by dissolving 6.81g monopotassium phosphate (KH_2PO_4) and 1.14g sodium hydroxide (NaOH) in 1L of deionised water.

Results and discussion

Method development for a loose wool feltability test at CSIRO

Reducing the volume of the felting medium (water or buffer) and increasing agitation time and temperature resulted in greater felting for all three agitation methods. When 100ml of felting medium was used in the Labomat, little or no felting occurred. This was presumably due to the cushioning effect of the liquor on the wool during agitation.

The tumble dryer and Laundrometer methods produced irregular shaped feltballs (Figures 1 and 2) and often the steel balls became encapsulated with in the actual felt ball. When steel balls were omitted from the test, no felt balls were produced. Shaping and rolling the 1g of wool into a ball shape prior to starting the felting test prevented the encapsulation of the steel balls. However the shapes of the felt balls produced using the tumble dryer and Laundrometer were still irregular. This may be due to the size and shape of the containers and/or the agitation style.

Figure 1: Feltballs produced using the tumble dryer method

Figure 2: Felt balls produced using the Laundrometer method

Solvent scouring in dichloromethane removed only the wool grease leaving behind the residual swint and dirt. Although passing the solvent scoured wool through a Shirley Analyser removed some of the loose dirt and dust, removing the remaining swint and dirt via an aqueous scour either before or after solvent scouring, did not improve the felt ball formation in the Laundrometer.

The Mathis Labomat method produced more uniform feltballs, particularly when the wool samples were shaped into 5-8cm diameter balls prior to felting. The inclusions of steel ball bearings were still necessary in order to produce spherical feltballs. Changing the felting medium from deionised water to ph 6.8 buffer did not influence the felt ball formation. However it was decided to continue using the buffer as the felting medium because of the intention to apply this felting test to wools produced in different regions of Australia that may differ in pH.

The Mathis Labomat method was the preferred method and all of the subsequent data has been collected using the Mathis Labomat.

1) Reproducibility of feltballs produced on Mathis Labomat at 40°C and 60rpm

The reproducibility of feltball size was determined on solvent scoured wool samples from the same source. The samples were felted in the Labomat in 50mls of buffer containing 25 x 1g steel balls. The Labomat was set at 40°C and agitated at 60rpm for either 30 or 60 minutes. The diameters of the resulting feltballs are shown in Table 1. The low variation in feltball diameter indicates that the test is reproducible under these experimental conditions. Well felted samples were easier to measure due to their increased density of the feltball. Great care was required in measuring the diameter of the low density feltballs because of difficulty in defining the edge of the feltball.

Table 1: Feltball diameter of solvent scoured wool felted for 30 or 60 minutes at 40°C with 60rpm agitation

Felting Time @ 40°C & 60rpm	Feltball diameter (mm) D1	D2	D3	D Average	Population Feltball Diameter	
60 minutes	29.80	21.93	20.21	23.98	Average	24.44
60 minutes	27.87	25.93	19.41	24.40	SD	0.58
60 minutes	26.59	22.67	20.43	23.23	CV(%)	2.38
60 minutes	28.39	23.55	20.62	24.19	C.I	0.38
60 minutes	28.43	26.45	19.40	24.76		
60 minutes	29.00	24.57	20.34	24.64		
60 minutes	28.89	25.77	20.19	24.95		
60 minutes	30.10	27.19	18.21	25.17		
60 minutes	28.96	27.18	17.80	24.65		
30 minutes	30.17	27.81	19.39	25.79	Average	26.20
30 minutes	29.45	29.43	21.46	26.78	SD	0.43
30 minutes	30.03	27.43	20.22	25.89	CV(%)	1.65
30 minutes	32.24	26.47	20.88	26.53	C.I	0.38
30 minutes	31.12	26.66	20.22	26.00		

D: diameter (mm); SD: standard deviation; CV: coefficient of variation; C.I: 95% confidence interval

2) Effect of agitation time and temperature on felting

The effect of agitation time on felting behaviour of a variety of wools including solvent scoured wool, control top sliver, chlorinated top sliver and chlorine hercosett top sliver was examined. Felting was carried out in the Labomat set at 40°C and 60 r.p.m using 50mls of buffer solution containing 25 x 1g steel balls. Under these conditions the control wool top sliver felted to more quickly than the other wools and the chlorine hercosett top sliver did not felt at all under these conditions (Figure 3). Therefore these Labomat conditions are sufficiently sensitive to distinguish the different felting ability of different wools. Agitation time has a significant effect on the felting. Using a logarithmic trend line, 95% of the variation in feltball diameter can be explained by felting time alone for each of the wool types. Figure 4 shows that felting temperature also influences felting, with the higher temperature producing a smaller diameter feltball.

3) Effect of fibre length and level of agitation on felting

Fibre length did not have a significant effect on felting propensity under the experimental conditions used in this trial regardless of whether fibres were cut from top sliver and agitated at 15 or 60 r.p.m (Figure 5), cut from 100mm long fibres (Figure 6) or half lengths of solvent scoured wool staples (Figure 7). This finding contradicts the findings of Liu and Wang (2007) who showed that fibre length contributed significantly to felting. We observed that 2mm snippets were able to felt in 50 mls of buffer containing 25 x 1g steel balls in a Labomat set at 40°C, and 60 r.p.m, albeit into 4 x 10mm diameter feltballs and some loose fibre instead of a single feltball (Figure 8).

Feltball Characterisation of INF greasy wool samples

It was evident that after solvent extraction in dichloromethane (DCM) some INF samples still contained dirt (see Appendix 1 for photographs). The Turretfield samples were the dirtiest whilst those from Kirby were relatively clean after solvent scouring. The feltball diameters of the INF wools after felting at 60 r.p.m and 40°C for 30 or 60 minutes are shown graphically in Figure 9. Figure 10 shows the actual feltballs generated after 60 minutes of felting. The feltball diameter data is summarised in Table 2 along with other fibre properties extracted from the INF database (Armidale). The Katanning wools had the highest felting propensity whilst the Kirby wool felted least.

Table 2: Fibre properties and felting propensity of selected INF wools

INF Identifier	Location	LAS FD (µm)	LAS CURV (°/mm)	RTC (MPa)	HAND	OFDA LENGTH (mm)	Feltball diameter (30 min)	Feltball diameter (60 min)
26IN072007070370	Turretfield	15.8	65	7	3	60	27.75	25.92
26IN072007070266	Turretfield	15.8	63	9	3	60	26.10	24.92
26IN012007070151	Kirby	16.70	79	11	4	60	28.06	26.22
26IN012007070604	Kirby	16.8	81	9	3	70	29.36	28.34
26IN082007070943	Katanning	17.7	50	8	4	70	24.67	23.86
26IN082007070708	Katanning	17.9	50	4	3	70	25.97	24.52
26IN032007000740	Cowra	18.6	68	11		60	27.49	25.96
26IN032007000789	Cowra	18.8	67	9		40	28.77	27.31

Las FD and Las Curv: Laserscan fibre diameter and curvature; RtC: resistance to compression

Correlation studies between fibre diameter properties and feltball diameter are shown in Table 3. Feltball diameter was most strongly related to fibre curvature and a weakly correlated to resistance to compression. Surprisingly no correlation existed between feltball diameter and fibre diameter.

Table 3: Correlation studies between fibre properties and feltball diameter for the selected INF wools

	LAS FD (μm)	*LAS CURV (°/mm)*	*RTC (MPa)*	*HAND*	*OFDA LENGTH (mm)*	*Feltball diameter (30 min)*	*Feltball diameter (60 min)*
LAS FD (μm)	1						
LAS CURV (°/mm)	-0.228332	1					
RTC (MPa)	0.045821	0.6904	1				
HAND	0.359573	-0.009594	0.49099	1			
OFDA LENGTH (mm)	-0.303766	-0.231313	-0.349603	0	1		
Feltball diameter (30 min)	0.017425	0.864368	0.406967	-0.281185	-0.440037	1	
Feltball diameter (60 min)	0.048712	0.848844	0.41159	-0.287089	-0.371076	0.973389	1

Las FD and Las Curv: Laserscan fibre diameter and curvature; RtC: resistance to compression

Conclusion

A robust and reproducible method of investigating the felting kinetics of loose wools has been established at CSIRO using a Labomat dyeing machine. Experimental conditions such as volume of felting liquor, the presence of steel balls and the level and time of agitation all influence the felting propensity. Agitation time had the greatest influence on felting, with longer felting times resulting in more felting and reduced feltball diameter.

The length of the fibre sample did not influence the felting performance of the top sliver or solvent scoured wool.

For the matched INF wool pairs, the sample with the higher RtC produced the smaller diameter feltballs. The Katanning samples, with the lowest fibre curvature produced the smallest feltballs and the high curvature Kirby samples felted the least. Fibre curvature was most strongly related to feltball diameter. Interestingly there was no observed correlation between feltball diameter and fibre diameter. For each of the matched pairs, the sample with the higher RtC produced the smaller diameter feltballs. The negative correlation between hand and feltball diameter was very weak, possibly due to the limited range of hand values available for the selected INF wools. Clearly more samples need to be tested to establish whether a correlation exists between hand and felting propensity. Also other fibre properties, such as scale height and frequency may play an important role in felting.

Figure 3: Effect of agitation time on felting of wools in 50mls of buffer in a Labomat set to 40°C and 60 r.p.m

Figure 4: Effect of agitation time and temperature on the felting of solvent scoured wool in 50mls of buffer in a Labomat set to agitate samples at 60 r.p.m

Figure 5: Effect of fibre length (cut control top sliver) on felting propensity in 50mls of buffer in a Labomat set at 30°C and agitated for 30 minutes

Figure 6: Effect of fibre length (cut from 100mm fibres) on felting propensity in 50mls of buffer in a Labomat set at 30°C and agitated for 120 minutes at 15 rpm

Figure 7: Effect of fibre length (full and half length solvent scoured staples) on felting propensity in 50mls of buffer in a Labomat set at 40°C and agitated at 60 rpm

Figure 8: Feltballs generated from 2mm wool fibre snippets, felted in 50mls of buffer in a Labomat set at 40°C and agitated at 60 rpm for 45 minutes

Figure 9: Felting propensity of INF wools in 50mls of buffer in a Labomat set at 40°C and agitated at 60 rpm

Figure 10: Feltballs from INF wools after 60 minutes of felting

References

Blankenburg, G. (1969) The industrial application of Felting and Milling tests for loose wool. *Wool Science Review,* 35**,** 24-34.

Chaudri, M. A. & Whiteley, K. J. (1968) Influence of Natural Variations in Fiber Properties on Bulk Compression of Wool. *Textile Research Journal,* 38**,** 897-906.

Chaudri, M. A. & Whiteley, K. J. (1970a) Influence of Natural Variations in Fiber Properties on Felting Characteristics of Loose Wool. *Textile Research Journal,* 40**,** 297-&.

Chaudri, M. A. & Whiteley, K. J. (1970b) Relationships between Loose-Wool Felting and Bulk Compressional Properties. *Textile Research Journal,* 40**,** 775-779.

Dowling, M. E., Greeff, J. C. & Schlink, A. C. (2005) Feltball diameter measurement lacks repeatability over the lifespan of a Merino ewe. *Application of new genetic technologies to animal breeding. Proceedings of the 16th Conference of the Association for the Advancement of Animal Breeding and Genetics, Noosa Lakes, Queensland, Australia, 25-28 September, 2005.*, Association for the Advancement of Animal Breeding and Genetics.

Elliott, K. H. & Lohrey, P. J. (1982) The loose wool felting properties of a range of New Zealand Wools *Wool,* 7**,** 21-25.

Fraser, R. D. B. & Pressley, T. A. (1958) Felting Investigations: Part I : Potential Substitutes for Rabbit Fur in Hat Felts.

Greeff, J. C. & Schlink, A. C. (2002) The inheritance of felting of Merino wool. *Wool Technology and Sheep Breeding,* 50**,** 6-10.

Kenyon, P. R. & Wickham, G. A. (1999) A New Technique for Measuring Loose-wool Feltability. *Journal of the Textile Institute,* 90**,** 266-267.

Kenyon, P. R., Wickham, G. A. & Blair, H. T. (1999) Natural Variation in Felting and Yarn Shrinkage in Wool from Romney and Romney-Cross Sheep. *Journal of the Textile Institute,* 90**,** 395-403.

Ladyman, M. E., Greeff, J. C. & Schlink, A. C. (2007) Feltability of Merino wool is influenced by scale structure. *Animal Production in Australia.* Victoria.

Liu, X. & Wang, X. (2007) A Comparative Study on the Felting Propensity of Animal Fibers.

Makinson, K. R. (1975) Surface properties of wool fibers

IN SCHICK, M. J. (Ed.) *Surface characteristics of fibers and textiles Part 1.* New York, Marcel Dekker, Inc.

Rippon, J. A. (2008) Friction, felting and shrink-proofing of wool. IN GUPTA, B. S. (Ed.) *Friction in Textile Materials.* Woodhead.

Schlink, A. C., Greeff, J. C., Ehni, J. & Denning, R. (2009) Using a bench-top rotor spinning system to measure variation between individual fleeces for predicting yarn and fabric characteristics. *Animal Production Science,* 49**,** 333-339.

Sumner, R. M. W. (2009) Relationships between softness and feltability with cuticle scale pattern and fibre dimensions within individual fleeces from six breeds of sheep. *International Journal of Sheep & Wool Science,* 57.

Veldsman, D. P. & Kritzinger, C. C. (1960) 93--Studies on the felting properties of South African Merino wools. *Journal of the Textile Institute (Transactions),* 51**,** T1257-T1273.

Zahn, H. & Blankenburg, G. (1962) The Influence of Weathering on Some Chemical and Physical Properties of Wool Fibers, with Particular Reference to Felting.