Electronic Supplementary Material (ESI) for Green Chemistry.

A review of the green chemistry approaches to leather tanning in imparting sustainable leather manufacturing

Supplementary Materials

Contents

Table S1. Tanning performance of leather treated by improved Cr tanning process.

Tanning agents	Type of leather	Tanning agent consumption (l/Kg)	Chemicals consumption (g/Kg)	Water consumption (l/Kg)	Shrinkage temperature (°C)	Tensile strength (MPa)/Elongation (%)/Tearing strength (N/mm)	Ref.
Chrome-tanning with other metals and zeolites							
BCS + FS	Cowhides	15.4 + 6.6	20.0	n/a	110.0	26.4 / 74.0 / 75.6	67
BCS + BAS + FS	Cowhides	11.0 + 7.7 + 3.3	20.0	n/a	109.0	24.7 / 53.0 / 81.0	
BCS + BAS + ZrS	Cowhides	11.0 + 7.7 + 3.3	21.0	n/a	119.0	43.0 / 84.0 / 79.1	
BCS + sodium zeolites (lab-scale)*	Pickled sheepskin	80.0 + 30.0	110.0	2.74	105.0	n/a	68
BCS + sodium zeolites (pilot-scale)*		76.4 + 30.0	116.4	0.93	104.0	24.4 / 46.0 / 94.0	
BCS + re-tanning with acrylic and phenolic syntans and fatliquoring*	Raw goatskin	80.0	-	-	110.0±1.0	25.6 ± 0.5 / 76.0 ± 3.0 / n/a	69
Cr tanning with Cr adsorption increasing additives							
BCS + PBA nanoparticle dispersion, then re-tanning/fatliquoring with syntan and sulphited oil*	Pickled cowhide	80.0 + 40.0	135.0	n/a	126.0±1.2	27.9 ± 0.6 / 84.0 ± 4.0 / n/a	32
BCS + oxazolidine	Cowhides	90.0 + 10.0	180.0	1.8	105.0±2.0	25.0 / n/a / 57.9	66
BCS + TLWP	Pickled cow pelt	60.0 + 60.0	140.0	1.0	106.0±0.5	27.0 ± 0.3 / 58.0 ± 1.0 / 57.0 ± 1.0	69
BCS + AVP-ZnO	Cowhides	35.0 + 30.0	165.0	n/a	92.4	n/a	70
BCS + AVP-ZnO, then re-tanned with the same	Cowhides	35.0 + 30.0/30.0 + 20.0	215.0	n/a	124.7	24.7 / 80.0 / 141.7	
BCS + AVP-MMT	Salted goatskin	30.0 + 20.0	n/a	n/a	104.3	16.0 / 76.0 / 55.0	71
BCS + HBAP	Pickled pigskin	80.0 + 40.0	350.0	n/a	107.5	n/a	73
BCS + RSTW-PEG	Cowhides Goatskin	60.0 + 50.0	n/a	n/a	n/a	24.1 ± 0.4 / 56.0 ± 1.0 / 49.1 ± 1.0	76
Cr adsorption increase by sonication							
BCS tanning under sonication (300 Watt/28 KHz) Cr* treatment using	Pickled goatskin	20.0 g/l[d]	n/a	n/a	105.2	13.8 / 40.1 / 56.2	77
Sonicated Cr treatment using BCS*	Cowhides	60.0 g/l[d]	n/a	n/a	104.5	n/a	80
Sonicated (150 Watt/40KHz) Cr* treatment using BCS	Pickled cowhide	50.0 g/l[d]	n/a	n/a	116.0±1.0	n/a / 33.2 ± 1.3 / 70.0 ± 4.0	81
Sonicated Cr treatment using BCS + microwave*	Pickled goatskin	20.0 g/l[d]	n/a	n/a	103.8	15.4 / n/a / 34.2	82
Waterless tanning							
Waterless tanning with BCS in propylene carbonate	Cowhides	50.0	70.0	0.15	100.0	n/a	88
BCS in SC-CO_2	Cattle skin	90.0 g/l BCS + 120.0 g/l NaCl + 5.0 m/l formic acid + 8.0 ml/l sulphuric acid for 2.5 hr under 6.0 MPa pressure[d]			100.0	n/a	91
Tanning in 2:1 urea and $KCr(SO_4)_2 \cdot 10H_2O$ deep eutectic solvent	Cowhides	The Cr content of leather was 3.52%			83.0	30.3 / 42.5 / n/a	92
Cr tanning in combination with tannins, syntans, resins, and other crosslinking agents							
Cr-syn/PAA/PMA, then fatliquoring	Delimed goat skin	15.0	80.0	1.5	118.0 ± 2.0	32.9 ± 1.0 / 78.0 ± 4.0 / 84.3 ± 5.0	33
Cassia alata tannin + BCS	Raw goatskin	65.0 + 25.0	145.0	n/a	95.0	12.0 / 53.5 / 49.2	34
(*Cassia alata* tannin + *Cassia alata* tannin induced Ag NP) + BCS	Raw goatskin	65.0 + 25.0	145.0	n/a	107.0	21.7 / 66.5 / 60.6	

Cr (III)-loaded nanoparticles of PEGMA-co-AA-co-GMA and then fatliquoring treatment	Pickled sheepskin	20.0[b]	243.0	7.3	101.5	12.4 / 98.8 / 30.5	38
Cr-acid complex formulation, then re-tanned/fatliquored with syntan	Wet salted goatskin	40.0	370.0	2.0	>100.0	23.3 ± 0.9 / 72.6 ± 1.2 / 68.8 ± 0.9	93
Pickling with oxazolidine + BCS	Pickled goatskin	40.0 + 70.0	130.0	n/a	107.5	22.9 / 82.7 / 71.2	94
BCS + acrylic resin/montmorillonite	-	60.0 + 20.0	160.0	2.0	89.0	17.7 / 8.9 / 29.1	95
BCS + SiNP-pMMA-BA (1% Si NP)	Pickled buffalo	30.0 + 40.0	170.0	2.0	100.0	48.5 / 72.0 / n/a	97
BCS + SiNP-pMMA-BA (5% Si NP)	hides	30.0 + 40.0	170.0	2.0	115.0	41.0 / 56.0 / n/a	
MgAl-LDH + BCS	Pickled goatskin	40.0 + 20.0	60.0	n/a	94.0±3.0	19.3 ± 0.6 / n/a / 26.1 ± 0.7	99

N.B. The calculation of BCS, BAS, ZrS, and FS was based on their Cr_2O_3, Al_2O_3, ZrO_2, and Fe_2O_3 contents respectively, and also the weight of wet skins.
[a] No re-tanning/fatliquoring treatment or fatliquoring but dosage was not provided.
[a] The authors did not provide re-tanning and fatliquoring chemical consumption provided.
[c] The nanoparticles contain 4% Cr. The dosage is equivalent to 20 g Cr/kg pickled wet leather containing 200% water.
[d] Soaked in this solution for 5 to 6 min.
[e] Calculated based on Cr content.

Table S2. Tanning performance of chrome-free leather tanned by chemical cross-linking.

Tanning agents	Type of leather	Tanning agent consumption (l/Kg)	Chemicals consumption (g/Kg)	Water consumption (l/Kg)	Shrinkage temperature (°C)	Tensile strength (MPa)/Elongation (%)/Tearing strength (N/mm)	Ref.
Glutaraldehyde + Tara tannin followed by re-tanning with polyaryl sulphonate	Pickled sheepskin	250.0	627.5	6.0	92.0±1.0	23.0 ± 1.8 / n/a / 51.0 ± 7.8	41
Syntan + Mimosa tannin + oxazolidine, and then fatliquoring/dyeing	Calfskin	150.0 + 40.0 + 200.0	494.0	9.5	98.0	16.6 / n/a / 44.0	42
Glutaraldehyde + Mimosa tannin + oxazolidine, and then fatliquoring/dyeing	Calfskin	10.0 + 40.0 + 200.0	354.0	9.5	104.0	21.0 / n/a / 50.9	
THPS + Tara tannin + glutaraldehyde, then re-tanned and fatliquored	Pickled sheepskin	15.0 + 100.0 + 20	475.0	3.5	88.0 ± 1.0	16.2 ± 0.5 / 58.0 ± 2.0 / n/a	111
Glutaraldehyde + syntan followed by re-tanning/fatliquoring with acrylic syntan and vegetable tannin[a]	Salted goatskin	25.0 + 20.0	213.0	n/a	85.0	15.6 / 44.1 / n/a	112
Glutaraldehyde tanning followed by re-tanning with melamine resin	Salted goatskin	110.0	110.0	0	90.0±4.0	15.0 ± 2.0 / 72.0 ± 6.0 / n/a	115
Lysine + glutaraldehyde and then re-tanning with melamine resin	Salted goatskin	10.0 + 20.0 + 40.0	85.0	0.5	120.0±8.0	18.0 ± 3.0 / 56.0 ± 6.0 / n/a	
Glyoxal	Pickled goatskin	60.0	60.0	n/a	82.0	n/a	116
EHBP-D + BAS	Pickled goatskin	80.0 + 60.0	340.0	2.0	108.6±1.1	15.0 ± 37 / 93.8 ± 6.3 / 30.6 ± 6.3	122
BDA + Acrylic resin + Amino resin + mimosa + BAS	Pickled sheepskin	20.0 + 30.0 + 20.0 + 40.0 + 10.0	320.0	19.5	88.0	17.5 / 85.0 / 15.0	127
THPS + syntan followed by re-tanning & fatliquoring twice	Salted goatskin	20.0 + 20.0 + 60.0 + 135.0	681.0	27.0	91.0	n/a / 28.5 / 28.4	128
POSS-NH_2 + THPS	Salted goatskin	60.0 + 25.0	90.0	n/a	83.0	17.1 / 102.2 / 74.5	129
HHTT-EGDE-CP	Pickled sheepskin	120.0	474.0	17.0	78.8	13.5 / 68.2 / 54.2	130
AEHET		120.0	464.0	17.0	75.7	7.9 / 73.4 / 23.9	
COS-GTE tanning followed by fatliquoring	Sheep hides	150.0	418.0	9.0	83.5	10.1 / 62.6 / 47.4	131
AAMV tanning, then re-tanning and fatliquoring	Pickled sheepskin	80.0 + 50.0 + 40.0	310.0	n/a	70.0	13.0 / 60.0 / 54.0	133
Tara tannin + BAS + glutaraldehyde, then re-tanning/fatliquoring with syntan	Cow upper skin	200.0 + 170.0 + 10.0 + 2.00	607.0	13.5	103.0	n/a	134

N.B. The calculation of BAS was calculated based on its Al_2O_3 content and also on the weight of wet skins.
[a] The chemical consumption does not include fatliquoring chemicals.
[b] No re-tanning and fatliquoring treatment.

Table S3. Tanning performance of chrome-free leather tanned by cross-linking with dialdehyde polymers.

Tanning agents	Type of leather	Tanning agent consumption (l/Kg)	Chemicals consumption (g/Kg)	Water consumption (l/Kg)	Shrinkage temperature (°C)	Tensile strength (MPa)/Elongation (%)/Tearing strength (N/mm)	Ref.
SAD + fat liquoring	Pickled sheepskin	80.0	212.0	34.0	89.4	22.1 ± 2.7 / 42.5 ± 7.0 / 114.6 ± 4.4	3
ZrS + oxidised starch (with 60% H_2O_2), then re-tanning with mimosa and syntans, and fatliquoring	Pickled cattlehides	175.0 + 48.0 + 70.0	590.0	30.5	87.3 ± 0.5	15.6 ± 0.7 / n/a / 76.9 ± 2.5	126
SPDA (4% solution) tanning followed by fatliquoring	Pickled sheepskin	80.0	250.0	13.0	79.0	19.7 ± 1.8 / 107.9 ± 8.1 / n/a	139
CMC-D + SAD	Pickled cattle pelt	40.0 + 7.0	47.0	n/a	81.0	n/a	140
SAD		7.0	7.0	n/a	79.0	n/a	
H-CMC + SAD		40.0 + 40.0	80.0	n/a	72.0	n/a	
CMC-D, then fatliquoring with synthetic fatliquor	Pickled cattlehides	40.0	100.0	10.0	78.8	7.07 ± 0.23 / n/a / 22.95 ± 0.31	142
CMC-D + chitosan		40.0 + 20.0	120.0	10.0	85,0	n/a	
CMC-D + chitosan, then fatliquoring with synthetic fatliquor		40.0 + 20.0	190.0	19.5	80,0	3.43 ± 0.60 / n/a / 16.16 ± 1.13	
CMC-D + LMC-III, then fatliquoring with synthetic fatliquor		40.0 + 20.0	190.0	19.5	80.0	12.7 ± 1.5 / n/a / 28.8 ± 0.5	
TGD	Pickled sheepskin	80.0	656.0	8.0	86.7	n/a	143
SAD		80.0	656.0	8.0	83.9	n/a	
CDD		80.0	656.0	8.0	82.0	n/a	
Al-m-CCA (equal to Al_2O_3) + ZrS	Pickled cattle pelt	15.0 + 40.0	215.0	1.0	84.5	12.1 / 25.0 / 37.5	144
Al-m-MCA (equal to Al_2O_3) + ZrS	Pickled cattle pelt	150.0 + 40.0	210.0	2.0	86.0	n/a	145
Zr-m-HCD + ZrS	Pickled cattle pelt	n/a + 20.0	n/a	2.0	75.2	n/a	146
Al-m-HCD (equal to Al_2O_3) + $ZrOCl_2$	Pickled cattle pelt	10.0 + 30.0	100.0	2.0	87.0	n/a	146
(SBCD) + re-tanning with syntan followed by fatliquoring	Salted goatskin	100.0 + 160.0	420.0	3.0	73.0 ± 2.0	19.9 ± 1.3 / n/a / 40.6 ± 0.9	147
CSD[b]	Pickled sheepskin	100.0	160.0	5.0	77.9	8.6 / 72.0 / 14.5	148
CSD-g-EGDE + HMTA[b]		100.0 + 5.0	165.0	5.0	85.2	10.9 / 85.0 / 29.6	
TA-d-PEG[b]	Cowhide	160.0	160.0 + $NaHCO_3$ for neutralisation	6.0	80.8 ± 0.2	15.3 ± 0.1/ 66.8 ± 0.2 / 44.2	149
CSD tanning followed by fatliquoring with several natural and synthetic fatliquoring agents	Pickled goatskin	200.0	350.0	9.0	61.0 ± 1.0	28.2 ± 2.9 / 72.9 ± 10.1 / n/a	150

N.B. The calculation of BAS and ZrS were calculated based on their Al_2O_3 and ZrO_2 contents respectively and also on the weight of wet skins.
[a] The chemical consumption does not include fatliquoring chemicals.
[b] No re-tanning and fatliquoring treatment.