# Influence of Retanning Agents on the Compostability of Leather

Volker Rabe, Jens Fennen, Biju Francis, Florian Doeppert
TFL Ledertechnik GmbH, Peter-Krauseneck-Str. 16, 79618 Rheinfelden, volker.rabe@tfl.com

## Abstract

The biodegradability of leather is gaining increasing attention in the context of sustainable material development, particularly regarding environmental compatibility and circularity. However, the actual extent and rate of degradation of leather are significantly influenced by the type of chemicals used in its manufacture.

This study investigates the role of retanning agents—a factor not yet thoroughly explored—in influencing the compostability of leather. By applying various retanning chemicals to a standardized chrome-free pre-tanned substrate, we evaluated composting behavior of such leathers. Results reveal that certain retanning systems significantly alter the disintegration profile and compostability of leathers, offering a potential pathway to optimizing biodegradability in leather production

Keywords: leather, compostability, retanning agents, biodegradability, PCMS, tannins, chrome-free tanning

## Introduction

In light of the growing importance of circularity, the biological degradability of leather is increasingly coming into focus in sustainable material development. As a protein-based natural material, leather fundamentally has the potential for biological decomposition. This gives leather the opportunity to position itself as a renewable raw material with good end-of-life performance.

While the influence of the primary tanning is now comprehensively studied, there are only few systematic studies so far on the influence of retanning. The aim of the present contribution is therefore to analyze the role of retanning agents in the context of industrial composting according to ISO 20200.

## Fundamentals: choice of disposal determines the test method

Biodegradable materials can be recovered materially, energetically, or through composting or digestion. The ecologically most efficient pathway depends on the specific waste stream and local conditions. For each of the different disposal pathways, various laboratory methods exist to evaluate if a given material is suitable for that disposal route.

For the measurement of degradation, testing methods with defined parameters (temperature, moisture, oxygen, physical state) have been developed. These can be classified according to the underlying disposal scenarios:

**Anaerobic systems (without oxygen):**

- Low temperatures: simulates conditions in landfills or soil (ASTM D5511).
- Higher temperatures: corresponds to biogas plants designed for methane production from digestible substances.

**Aerobic systems (with oxygen):**

- **Dry systems:**
  - Low temperatures: home composting (UNI 11183).
  - Higher temperatures: industrial composting (ISO 20200).
- **Aqueous systems**:
  - Low temperatures: wastewater treatment plants or natural waters (ISO 20136).
  - Higher temperatures: thermally active reactor systems.

For leather, industrial composting is regarded as the preferred disposal pathway. The process – mechanical breakdown (disintegration) and microbial degradation (bioassimilation) – is comprehensively covered by ISO 20200 and ISO 20136.

Use in biogas plants after pretreatment is also possible[1], [2], but currently not widely used. Home composting or direct incorporation into soil is possible but impractical due to slow disintegration – similar to thick pieces of wood or cardboard.

## Biological Degradation and Compostability

Biological degradability refers to the microbial breakdown of a material into $CO_2$, water, and biomass. The biological degradation process is subdivided into three phases:

- **Biological decay** – initial decomposition phenomena caused by microbial activity, such as discoloration or structural changes.
- **Biological disintegration** – advanced degradation where the material breaks into smaller fragments.
- **Bioassimilation** – the organic residues are converted into biomass, $CO_2$, and water.

In distinction to complete biological degradability, the compostability of a material — i.e., the breakdown of material into small fragments — only covers stages 1–2. However, this compostability is the basic prerequisite for integrating a biological material into a technical recovery pathway, i.e., supplying it to an industrial composting unit.

For evaluating compostability, the ISO 20200 method is used. This simulates industrial composting on a laboratory scale and tests the disintegration of materials over a period of up to 180 days. The method is based on placing the material in standardized synthetic compost consisting of sawdust, sugar cane, rabbit feed, mature compost, corn starch, corn oil, and urea, in sealable plastic containers under controlled conditions. The method is cost-effective, reproducible, and well suited for laboratory use. It allows comparative evaluation of differently treated materials with respect to their physical decomposition under industrial compost-like conditions due to its standardized compost composition.

The test is conducted in two consecutive phases:

- Thermophilic phase: 90 days at 58 °C
- Mesophilic phase: a further 90 days at 25 °C (optional if criteria are not met after the first phase)

A material is considered disintegrated if, after sieving through a 2-mm mesh, less than 10% of the original mass remains as residue.

## Compostability of Tanned Leather

Several studies, including Flowers et al. (2024)[3] and Escabros et al. (2023)[4], show that the primary tanning has a decisive influence on the compostability of leather. Chrome-free tanned leathers (glutaraldehyde) show very good, chrome-tanned leathers a good disintegration. Vegetable-tanned leathers show a mixed picture: leathers tanned with hydrolysable vegetable tannins (tara, chestnut, myrobalan, sumac) are very well compostable, while leathers tanned with non-hydrolysable (condensed) vegetable tannins (mimosa and quebracho) are relatively poor.

The literature also documents that certain retanning processes — particularly in shoe upper leathers — significantly reduce compostability. Sardroudi et al. (2024)[5] showed via ISO 20200 tests that retanning strongly influences disintegration. Chrome-tanned leathers disintegrated by 84%, while a retanned variant reached only 64%.

## Influence of Retanning on Compostability

As part of our own investigations, the influence of retanning on leather compostability was analyzed. The starting material was a uniformly chrome-free leather tanned with polycarbamoyl sulfonate (PCMS). This pre-tanned material was treated with two different retanning systems:

- Variant A: standard retanning
- Variant B: retanning with a high proportion of bio-based products

After treatment, the resulting leathers showed a biogenic content of 77% (variant A) and 81% (variant B), illustrating the influence of the chosen retanning chemicals on the biological content of the leather (see fig. 1). Both variants were tested according to ISO 20200. In both cases, after the thermophilic phase, disintegration was 100%, indicating no negative influence of the retanning on the compostability of these leathers.

| Tested materials | Retanning | $C^{14}$ | Thermophilic Stage (90 days) Disintegration rate in % | Mesophilic Stage (90 days) Disintegration rate in % | > 90% Disintegrated |
|---|---|---|---|---|---|
| PCMS | - | - | 100 | Test terminated | yes |
| PCMS | A | 77 | 100 | Test terminated | yes |
| PCMS | B | 81 | 100 | Test terminated | yes |
| GA | A | 76 | 83,53 | 85,24 | no |
| GA | B | 80 | 90,73 | 93,21 | yes |
| Cr | A | 83 | 19,08 | 21,68 | no |
| Cr | B | 88 | 42,61 | 43,98 | no |

Fig.1 Results of Biodegradation test of different leathers according ISO 20200

For other tanning systems, a more differentiated picture emerged. A leather tanned with glutaraldehyde (GA), retanned with variant A, reached only 85% disintegration after the mesophilic phase, missing the ISO requirement of 90%. Retanning with variant B raised this to 91% — sufficient to meet ISO 20200 requirements already after the thermophilic phase. This shows that the choice of a suitable retanning system can be decisive for passing the compostability test.

Also, in chrome-tanned leathers, improvement was achieved by selecting the retanning agent: disintegration increased from 22% (variant A) to 44% (variant B). Nevertheless, both chrome-tanned variants clearly failed to meet ISO 20200 requirements, underlining the dominant influence of the primary tanning on compostability.

In summary, retanning has a measurable influence on compostability. Although it plays only a secondary role compared to primary tanning, it can decide at borderline cases between passing or failing the composting test.

## Influence of individual retanning agents on Compostability

A differentiated assessment of individual retanning agents is not possible with the previous results. Therefore, in this study, in a test series (series A), a chrome-free leather pre-tanned by a PCMS system was specifically treated with different retanning agents. The choice of the PCMS system was based on its previously demonstrated excellent degradability, enabling a mostly unbiased evaluation of the used retanning agents.

In retanning, 30% of a tanning agent (based on shaved weight) with known tanning effect was applied. Three vegetable and two synthetic products were used, covering a broad spectrum of tannin types. A more differentiated classification of vegetable tannins than traditionally used in tanning practice was applied following current literature[6], dividing into four main groups (see fig. 2):

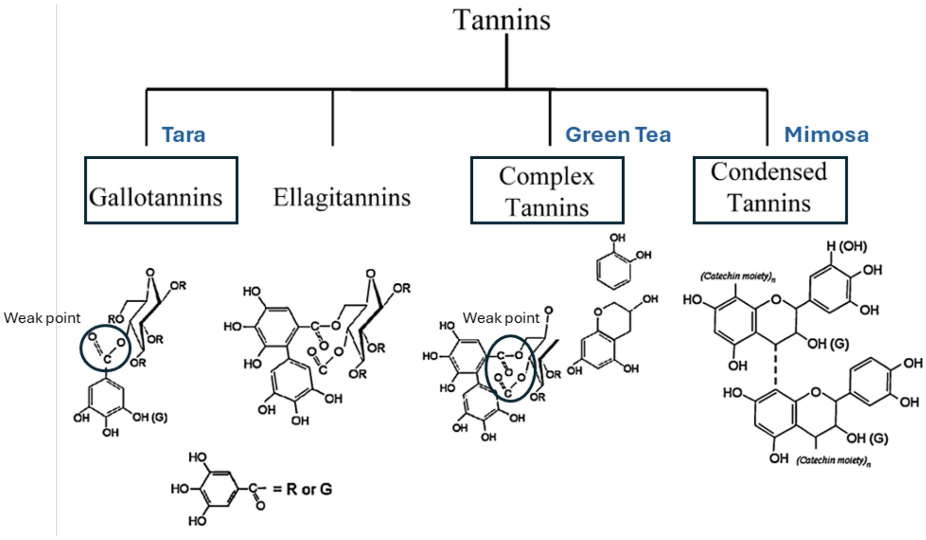


Fig. 2 Classification of the four different classes of tannins

- Gallotannins: easily hydrolysable; composed of organic acids (e.g., gallic, digallic or chebulic acid) bound to glucose.
- Ellagitannins: also hydrolysable, containing ellagic acid units; regarded as more stable than gallotannins.
- Complex tannins: formed by combination of gallic or ellagic acid with catechins or glucosides; combining properties of hydrolysable and condensed tannins.
- Condensed tannins (proanthocyanidins): not hydrolysable; consist of polymerized flavonoids and are particularly difficult to degrade.

To represent these groups, tara (gallotannins), mimosa (condensed tannins), and green tea (complex tannins) were chosen. Additionally, two synthetic tanning agents were used: a new generation low bisphenol (NG) and a classic syntan.

All treated leather samples were subjected to a composting test based on ISO 20200 but evaluated already after 20 days. The results show clear differences in disintegration (see fig 3):

- The tara-retanned leather was almost fully decomposed after 18 days — only a slight delay of two days compared to the untreated reference.
- Retanning with mimosa strongly inhibited disintegration; after 20 days, degradation was only about 10%.
- Green tea, as a complex tannin representative, showed no inhibitory effect: it was fully degraded after 16 days — comparable to PCMS-tanned leather.
- The synthetic tanning agents behaved differently: NG syntan achieved about 90% disintegration, while the classic syntan behaved similar to mimosa with strong inhibition (~10% disintegration).

Thus, syntans fall between hydrolysable and condensed tanning systems. The limited number of syntans tested does not allow general statements about their compostability; further systematic studies are required.

In further test series (series B and C), the PCMS leather was additionally treated with 30% tara together with 10% of a non-crosslinking auxiliary substance — either a polymer (series B) or a filler (series C). All samples still showed disintegration >95%, indicating that non-collagen crosslinking additives hardly or only minimally affect degradation behavior.

| Amount | sample | Type | Disintegrated after 20 d | Disintegrated by Day | shrinkage temperature |
|---|---|---|---|---|---|
| 6% | PCMS Std. | Organic | 100% | **16** | **74° C** |
| **A** | | | **Retanning** | | |
| 30% | Tara | Hydrolysable | 100% | 18 | **82 °C** |
| 30% | Green Tea | Complex | 100% | 16 | **83°C** |
| 30% | Mimosa | Condensed | 10% | - | **88°C** |
| 30% | Syntan | NG | 90% | - | **77°C** |
| 30% | Syntan | Classic | 10% | - | **79°C** |
| **B** | | | **Retanning (30% Tara each) + Polymers** | | |
| 10% | Std. Poly. | Polymer | 100% | 17 | - |
| 10% | Biopol. A | Biopolymer | 98% | - | - |
| 10% | Biopol. B | Biopolymer | 95% | - | - |
| **C** | | | **Retanning (30% Tara each) + Fillers** | | |
| 10% | Std. Filler | Filler | 95% | - | - |
| 10% | Biofiller | Biofiller | 100% | 16 | - |

Fig. 3 Results of the differently retanned leathers

A possible explanation lies in the stabilizing effect of tanning agents on the collagen structure, often evidenced by an increase in shrinkage temperature. For example, mimosa had in this case the highest shrinkage temperature at 88 °C, while tara (82 °C) and green tea (83 °C) were lower. This would initially suggest higher stabilization lead to reduced degradability. However, this cannot be the only effect to be considered, as the classic syntan showed relatively low degradability despite a lower shrinkage temperature (79 °C).
The higher degradability of chrome tanned leather compared to leather tanned with condensed tannins reported in other studies[3, 4] – with its shrinkage temperature of over 100°C for chrome – also does not appear to support a strict relation between the strength of the crosslinking and compostability.

## Hypothesis

An alternative explanation considers the chemical degradability of tanning agents by microorganisms. Hydrolysable and complex tannins contain ester groups that can be cleaved (see Fig. 2, weak points), whereas condensed tannins lack this structural vulnerability. As a result, hydrolysable and complex tannins can be more readily degraded, leading to a weakening or reversal of collagen crosslinking. A similar behavior is observed for chrome-free systems such as glutaraldehyde and PCMS.

- Glutaraldehyde forms Schiff bases with collagen, which microorganisms can cleave.
- PCMS systems crosslink collagen via polyurea groups[7], regarded as biodegradable at least in low-polymer forms[8] .

The higher biodegradability of chrome-tanned compared to condensed vegetable-tanned leather, despite the intrinsic resistance of chrome complexes, can be explained by differences in the type of collagen crosslinking.

Hydrogen bonds formed by plant-based tannins tend to shield collagen peptide bonds from enzymatic attack. In contrast, chrome salts mainly interact with side chains (carboxyl groups), leaving the peptide backbone accessible to enzymatic cleavage (see Fig. 4).

Together, these two mechanisms — structural hydrolysability and collagen crosslinking mode — provide a consistent explanation for the observed degradability differences. This clarifies why condensed tannins strongly restrict compostability, while non-crosslinking additives have only minor effects.

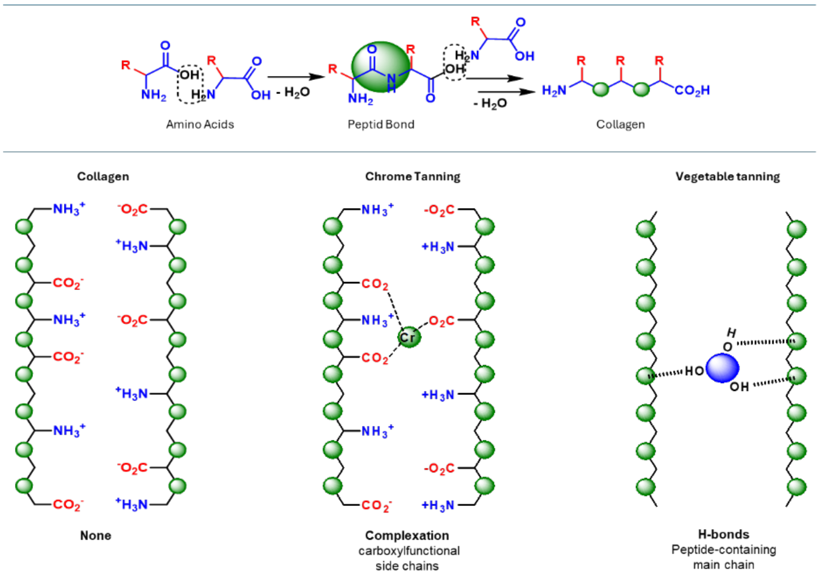


Fig. 4 Simplified overview of the different crosslinking reactions of tanning agents with collagen [10]

## Conclusion

This study demonstrates that retanning agents can substantially influence compostability of leather. Hydrolysable and complex plant tannins such as tara and green tea, as well as a new generation low-bisphenol syntan, showed only limited effects on disintegration under composting conditions. In contrast, condensed tannins like mimosa and a classic syntan strongly inhibited degradation. These differences appear closely linked to the molecular structure and the type of collagen crosslinking induced by the retanning agents.

In particular, systems that stabilize collagen while remaining themselves more easily degradable tend to be compatible with microbial breakdown, whereas stabilizing but less degradable systems reduce compostability. Additives with little or no collagen interaction, such as fillers and polymers, showed only minor influence on degradation rates.

Overall, the results highlight the importance of selecting appropriate retanning systems to enhance leather's end-of-life performance and to enable more sustainable disposal routes such as industrial composting. Future leather formulations should therefore consider not only functional performance but also the biological degradation profile after use.

## Acknowledgements

The authors would like to thank the entire TFL team for their extensive support in carrying out numerous practical leather processing trials. Special thanks go to Petra Balbo, Sabine Dickhaut and Roman Eichler, for their dedicated work and expertise. For external scientific advice and helpful discussions, we sincerely thank Karl Flowers.

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