innoTRAC Journal
Volume 3 (2024), pp. 108–116
https://doi.org/10.14464/innotrac.v3i1.774

Textile chains for load-bearing applications

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Received 02 September 2024; Accepted 05 September 2024; Available online December 2024

ABSTRACT Load-bearing transport and securing elements are essential components in modern industrial applications. Chains, known for their space-saving interlocking mechanisms, low weight, and safety features, play a critical role in load bearing and lashing capacities. This research, conducted by the Institute of Materials Science (ifm) at Hof University of Applied Sciences, focuses on a patented braided textile chain (WO2018153813 A1) that offers significant advantages over traditional metallic chains, including reduced weight, buoyancy, and minimized noise and spark emissions, alongside lower production costs. The project's objective was to validate the textile chain, enhance its breaking load to three tons, and achieve Technology Readiness Levels (TRL) 5 and 6. This was accomplished through several key developments: - Adaptation of the yarn insertion techniques (TRL 4) - Modification of pattern techniques and machine parameters (TRL 4) - Validation of core and inlay yarns (TRL 4) - Development of cutting, finishing and end-sealing processes (TRL 4). TRL 5 and 6 were verified through comprehensive testing in relevant application environments.

KEYWORDS Variation braider, textile chain, braiding pattern, bifurcated braids

1. Introduction

The main objective of this project was the continuous production of a textile chain that is on par with a product made from woven, sewn-together ribbons but can be manufactured with less effort. A particular focus here was on the special chain-like features such as space-saving interlocking, individual hooking and the possibility of varying the length of the required chain link. The model here was the conventional steel link chain. The combination of the characteristics of the steel chain with the textile properties results in a product with very good strength combined with a very high lightweight construction effect, which is significantly softer and lighter and thus avoids damage to people, machines and the environment. Due to the continuity and repeatability of the production process, the variation braiding technique is used. The result to be validated is property right WO2018153813 A1, which patents a binding technique and manufacturing method for a loop structure with a focus on use as a textile chain. The results presented here form the basis of the validation with the aim of a successful market launch with higher load-bearing loads and the prescribed safety factor of 7, which is mandatory for textile lashing. During the project, new braided bindings in basic and bifurcating pattern were developed and tested for this purpose, which also enable the interlock behaviour of the chain link structure. A further development step towards the textile braided chain was the investigation of additional material-introducing threads such as inlay and core yarn systems (positioning, number, combination). After defining the braided structure, attention was directed towards the processes involved in the continuous production of the system. The "lashing strap" and "hoist" applications were simulated in parallel to obtain comparable values. Both variants produced a positive result: the five-link chain elements successfully withstood both ratchet and crane lifting applications. As a result of the tests, there was a lower elongation with a higher residual breaking load due to the pre-tensioned samples compared to unloaded standard samples. Furthermore, the influence of weathering and UV light on the samples (TRL6) was also investigated at the end of the project, which led to a significant reduction in the overall load. Overall, the topic was nevertheless raised to TRL6 with a restriction to the loads adapted for the automatically processable braiding material. TRL4 was achieved with the targeted 3 t in a manual braiding process but cannot be implemented automatically with the currently available braiding machines due to insufficient spring tensions. Nevertheless, the project was successfully completed with positive results and all milestones were achieved. The defined goal of continuous production of a textile chain was reached. The high lightweight construction effect through the textile braiding production of the chain link structures was also achieved. Due to the continuity and repeatability of the process as well as the results of the present validation, there is also a clear economic advantage compared to previous studies. As a concrete continuation of the topic, the market launch of the textile chain product is imminent. The next measures to be taken for this are to optimize the automation of the overall process, in particular the separation and end sealing process. Furthermore, new braiding machines at ifm can be used to increase the number of braided, inlay and core yarns and to expand the binding technology in the branching area.

2. Methods

Within the framework of this project, 13 work packages (WP) were processed.

2.1. Evaluation and parameter defining (WP1-4)

WP1 and WP2 (project management and research) ran continuously throughout the entire funding period. In WP3 (trial and test planning), the following sizes of the chain links to be produced were evaluated and defined at the start of the project:

– **Dimension of the braided samples:**
  100 mm length of the individual chain links,
– **Base material:**
  UHMWPE (ultra-high molecular weight polyethylene) and polyester
– **Choice of machine:**
  Variation braiding machine VF1/(4-32)-140 from Herzog GmbH with 4x4 horn gear arrangement,
– **Test method:**
  Loop tensile tests based on DIN EN ISO 2062 with the result values maximum tensile force and fineness-related maximum tensile force.

The focus of the fourth WP was the adaptation of the yarn used in TRL4. The following yarn variants were examined for the selection of a suitable yarn type: UHMWPE yarn as a single thread (starting material), 12-thread UHMWPE rope in diameters of 1 and 2 mm, 2-thread ply UHMWPE yarn, twisted yarn with 60, 90 and 120 rpm. Depending on the variant, both the yarn and the braiding properties can vary accordingly. In this project, UHMWPE yarn is used in its single-thread basic form as the material due to its highest fineness-related maximum tensile force in the braided state.

2.2. Developing of braiding patterns and the braiding process (WP5-7)

The focus of WP5 was on developing the braiding patterns. Initially, four new patterns were validated: standard chain link pattern, small circle, large circle and square braid (see Fig. 1).

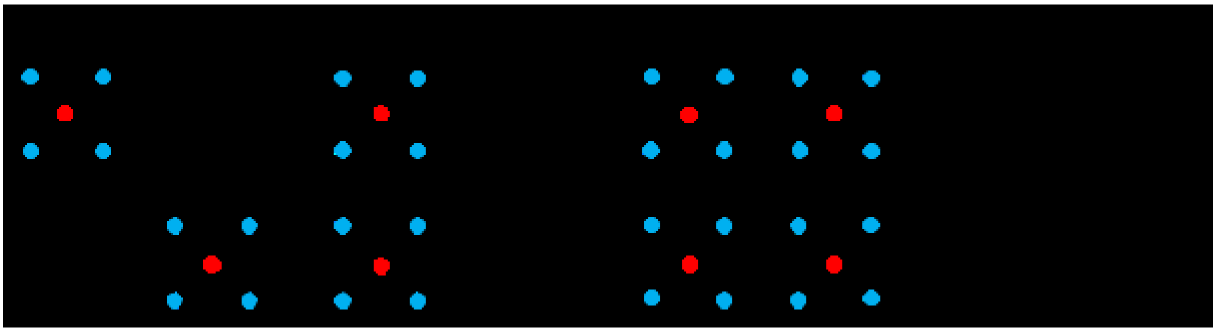


Fig. 1: Path images of the four braiding variants with inlay (blue) and core thread position (red)

These can be used in different settings (full and half setting). The full setting (1 bobbin position occupied, 1 empty) corresponds to 32 bobbins for the large circle braid and 16 bobbins for each of the other three variants. Corresponding loop tensile tests were also conducted. For the 4x4 variation braider, only the standard chain link pattern is suitable for accurately representing a real textile chain in terms of braiding technology. This pattern alone can create the interlocking behaviour of the two partial braided strands essential for the textile chain, using a second braiding pattern along the secondary axis (see free horn gears in Fig. 1 - standard chain link pattern). Additionally, a comprehensive material analysis was conducted using various yarn types (single yarn material, shedding, rope, twisting, wrapping). To achieve an optimal braided structure, the adjustable braiding parameters (speed, take-off speed, lay length, braid density, take-off force, bobbin spring force, stretching) were validated.

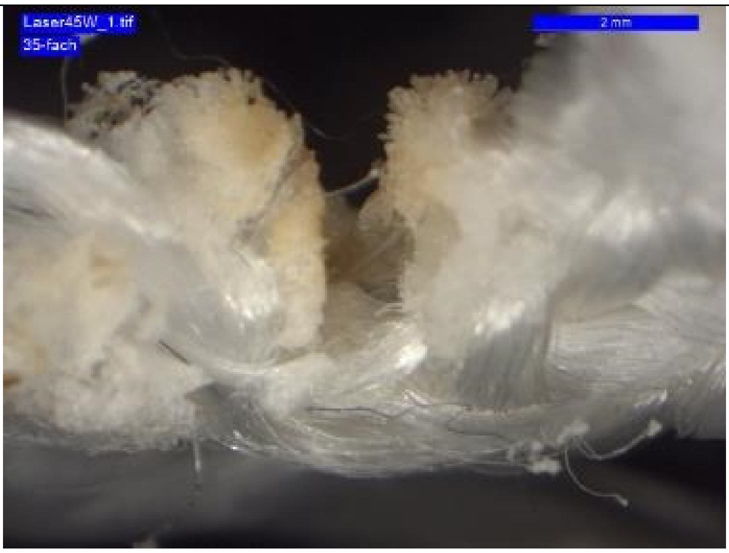
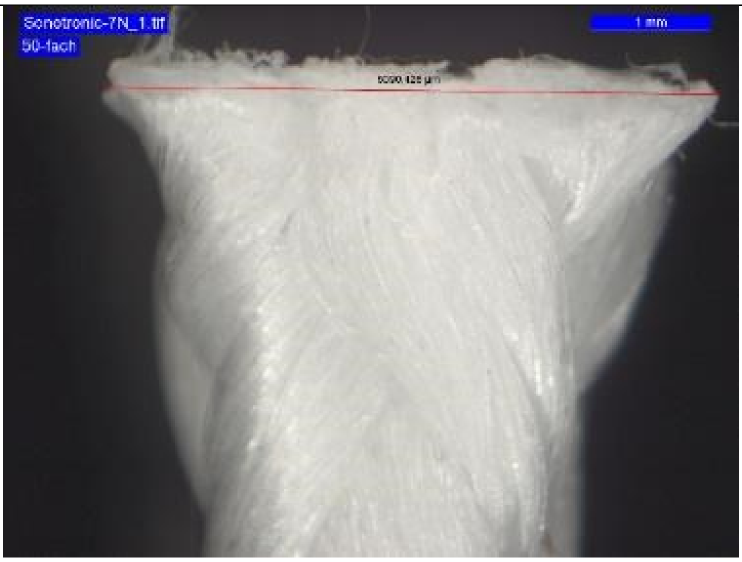
In the next WP6, the machine parameters were adjusted and evaluated. The focus here was particularly on the validation of the spring tension (150 – 600 g) and machine and take-off speed (20 – 60 mm). Four types of springs with corresponding tensile forces were used to evaluate the influence of the dished spring tension. Additionally, the potential influence of lay length variation was investigated. The lay length refers to the length of the braid produced during one complete pass of a bobbin through the repeat cycle until it returns to its starting position. For each partial braid examined, the optimal lay length, which maintains a constant braiding point height, was determined.

In the seventh WP, the influence of inlay and core threads (individually and in combination) on the braid was examined. Eight individual threads were used as core yarns for each position, with one thread designated for each inlay thread (see Fig. 2, shown in red and blue). The individual braided bonds were also subjected to tensile testing and the number of broken threads was recorded and evaluated.

2.3. Producing a braided textile chain, sealing the ends (WP8-9)

In the subsequent work package (WP8), methods for separating the interlocking chain links (which are braided together and need to be cut apart) and sealing the chain ends were explored. The following processes were considered: adhesive bonding, hot cutting, laser and ultrasonic cutting. The process parameters such as performance, process speed and sample preload were also examined and compared. Following a thorough analysis and testing (as shown in Table 1), along with comprehensive optimization tests, the following parameters were established: A chain structure made from UHMWPE material, characterized by high spring and pull-off forces as well as lay length and without inlay and core threads, is produced. The assembly involves the simultaneous separation and sealing of the braided ends using a hot cutting process. Test setups were developed in an operational environment (TRL 5 and 6) to assess the chain structure's performance in real-world applications.

Table 1: Comparison of the process variants for cutting to length and end sealing

Process	Picture
Hot cutting	
Laser cutting	
Ultrasonic cutting	

WP9 also concentrated on the sample ends, evaluating two end assembly processes. In the pull-in process using splicing needles, the excessively long braid ends are pulled back into the core. This method not only creates the conventional chain link structure but also enhances the overall strength of the system.

2.4. Optimization and weathering and UV light exposition, practical test environment (WP10-13)

WP10 details the parallel testing and results documentation.

WP11 focused on developing and conduction comprehensive optimization tests, representing the ideal of all work packages.

In WP12, the different variants were employed in a realistic test setup for lashing and hoisting systems.

Finally, in WP13, the samples were subjected to weathering and UV light exposure according to DIN EN 4892-3 to simulate real operating conditions.

Additionally, two practical test setups were constructed on-site to further evaluate real-world applications, as shown Fig. 2 and Fig. 3.

Fig. 3: "Lashing strap" test setup with two five-link textile chain strands

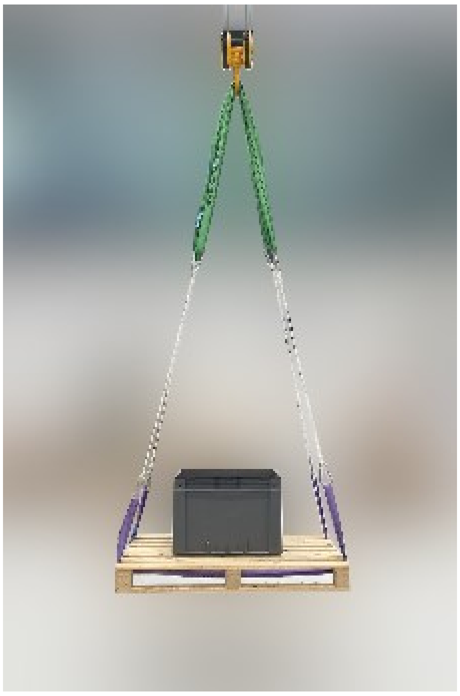


Fig. 2: "Hoist" test setup with four five-link textile chain strands

3. Results and Discussion

The results are as follows: In term of maximum tensile force, the yarn variants in rope form (from WP 4) achieve the highest force values due to the greater number of threads. However, their fineness-related maximum tensile force is lower compared to the thinner yarn variants. This is attributed to the manual braiding (with individual 90° steps of the braiding handwheel) and the resulting increased ondulation in the braid. The spring forces of the bobbins are insufficient to pull the braiding yarns effectively into the braid. Additionally, it was observed that the maximum tensile force of the raw starting material with a single thread is about half of that achieved with yarn variants using two UHMWPE threads.

The development of the braiding pattern reveals that the large circle binding variant with a full set delivers the best tensile results due to having twice the number of threads. Among the other variants, the small circle pattern is preferred because its maximum tensile strength, in terms of fineness, is significantly higher than that of the other patterns. This advantage is attributed to the pattern structure: the threads are positioned much closer together and each carrier path has a uniform bobbin lay length.

For the other braiding variants, a braiding machine with a larger braiding bed and therefore a higher number of horn gears (6x6 or 8x8) would be required. This project focuses on the standard chain link, small circle and large circle braids. The square braid variant due to its non- homogeneous pitch, would only be partially comparable to the other braids.

The investigation into the influence of the spring force in the range of 150 g to 600 g revealed only minimal effects. The standard deviations did not provide a clear conclusion and were roughly similar across the board. This finding was consistent for all braiding variants. However, in the subsequent phases of the project, springs with the highest tensile force were selected. This choice is based on the following theoretical principles: higher spring forces produce a tighter and denser braid with reduced ondulation. Consequently, choosing the strongest spring type also leads to material and cost savings.

The forces measured for samples with varying lay lengths (i.e. the ideal lay length in the partial braid) were only slightly higher than those for the standard variant with the consistent lay length across all braided areas. This suggests that gradually changing the lay length during the braiding process could be beneficial. However, the technical programming complexity involved in implementing this change outweighed the marginal improvement in values, leading to the decision to forego this optimization step in the project.

The pattern incorporating inlay and core yarns revealed that the number of broken threads increases with a longer partial braid. For core yarn variants, either all yarns break or none do. In the combination variant with both inlay and core threads, most often, all braiding and core threads break, leaving only the inlay threads intact in the broken braid. This suggests that the braiding structure has weak points due to friction and ondulation, with inlay threads contributing to stronger axial regions. Additionally, the fineness-related tensile strengths of these variants are not significantly higher than those of the original braids without inlay and core threads. Overall, while it is true that adding more material in the form of inlay or core threads generally results in greater (axial) strength and higher absolute maximum tensile forces, this does not always translate into significantly improved performance.

By securing the ends, it was determined that manual hot cutting was the most effective option for the project. This is because it combines cutting and sealing into a single step, eliminating the need for a two-stage process.

During the evaluation of the pull-in process, it was found that the strong fraying of UHMWPE material necessitated switching to PET threads. Despite UHMWPE's higher thread strength, no frictional connection can be seen compared to PET or the twisted material due to its smooth surface structure, resulting in no significant increase in chain strength. Additionally, the lay length of the braid was increased, and the partial braid was lengthened to ensure the structure was sufficiently loose and long for the pull-in process.

As a result of the WP1-11, it has now been proven that a load capacity of three tons can be achieved with UHMWPE rope (2 mm diameter) as the braiding material. Currently, this can only be attained manually due to the low spring tension. Consequently, subsequent tests focused on the automated braiding variants, which achieved a maximum load of 900 kg. With a larger variation braider, it is possible to fully exploit this potential and produce a continuous load-bearing textile chain with a capacity exceeding three tons.

The weathering and UV light tests revealed a substantial decline in tensile strength. The UHMWPE material shows a notably faster loss of strength compared to PET.

The results indicate that the samples experience less stress in the hoist application compared to the lashing strap application. The elongation values are significantly lower than those of the standard specimens, due to the prolonged holding of the specimens (both force-based and displacement-based), which preloads them with a pre-elongation. The structure and material of the braided specimens do not permit any elastic behavior.

4. Conclusion

The investigation into the textile chain performance has provided valuable insights. It was demonstrated that the manual hot cutting process is the most effective method for securing braid ends, as it simultaneously cuts and seals, thereby simplifying production. The project confirmed that a load capacity of three tons can be achieved with UHMWPE rope in manual conditions, though automated braiding currently limits achievable loads to 900 kg.

Additionally, the textile chain's performance in hoisting applications demonstrated less stress and lower elongation compared to lashing applications. These results highlight the importance of optimizing both the braiding process and the textile chain structure to enhance performance and durability. Future work should focus on refining automated braiding techniques and improving the overall robustness of the textile chain in practical applications. Nonetheless, both application areas were successfully implemented and exhibited reliable performance.

In the future, following the successful completion of this project, the Institute for Materials Science at Hof University of Applied Sciences will acquire new variation braiders. This acquisition will enable advanced mechanized exploration and thorough re-evaluation of the unresolved issues identified during the project, thereby enhancing capabilities for detailed investigation and improvement in the field. Additionally, there will be a focus on further developing and expanding internal expertise and maintaining a leading position in the domain of braiding, with particular emphasis on variation braiding techniques.

Acknowledgement

We gratefully acknowledge the financial support provided by the Bavarian Ministry of Economic Affairs, Regional Development and Energy, which was instrumental in advancing this research. Special thanks are extended to our collaborators and industry partners for their valuable feedback and continued support. Their contributions were crucial for the successful completion of the project.

The responsibility for the content of this publication lies with the authors.