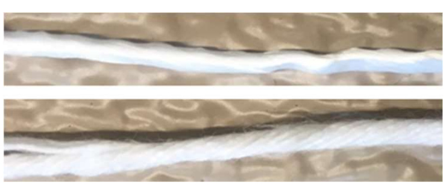
In-situ mechanical characterization of industrial hosing performance

R. Sourki, B. Crawford, T. Olfatbakhsh, A. Rashidi, J. Héraud (Niedner), M. Bureau (Sanexen), A.S. Milani*

Introduction

Woven fabrics are used in a wide variety of structural applications, including inflatable structures, consolidated composites and many others. These materials offer a superior combination of properties that address application-based needs, particularly via high strength-to-weight and stiffness-to-weight ratios, stability and formability [1, 2]. However, the architecture of dry/prepreg woven fabrics makes it difficult to understand their mechanical behavior, which is far from being fully understood. Further, the highly discontinuous nature of these materials also lends it the ability to generate structural defects such as in-plane misalignment, out-of-plane wrinkles, and so on [3-6].

Technical challenges associated with these materials has led to subsequent risks for manufacturers that use them. For example, continuous woven hoses made by the circular weaving process are imbalanced, by virtue of the two yarn directions never being truly orthogonal to each other. Additionally, each of these two yarn-wise directions in each of the two jackets, have different morphology, as shown in Figure 1. Despite the many advantages offered, the mechanical properties of the final structure are somewhat uncontrolled and unknown. This causes the stress and strain states of the structure to further develop in the field, ultimately presenting itself as defects that inhibit seamless product use. This activity is part of a larger effort to numerically model the hose systems, validated by in-situ experimental data. This forms the case study for the proposed research of characterizing woven fabric hydraulic hoses.



(a)

(b)

Figure 1. The (a) continuous and (b) discontinuous unsaturated polyester yarns used in the construction of the inner and outer jackets via the circular weaving process.

Defects and In-situ Testing

The woven hose products have the potential to develop in-situ defects that limits product performance, ultimately consuming time and resources to rectify. Two of these defects are referred to as snaking and bunching. The former is characterized by the axial buckling of the hose structure once pressurized, causing interference with other personnel or equipment on the worksite. The latter is the accumulation of plastic strain in either one of the two jackets, leading to this excess length bunching together. In the case of bunching in the external jacket, transportation, storage and general movement of the hose is more difficult. For bunching of the internal jacket, this can restrict the flow of the working fluid inside and severely reduce product performance. Both defects require bringing the hoses out of service and performing maintenance work, so it is highly desirable to understand the root causes of these complex phenomena towards product design and optimization. Figure 2 provides a visual example of snaking the bunching.

(a) (b) (c)

Figure 2. Examples of the in-situ defects experienced by the woven hose products. These are (a) snaking, in which case local and uncontrolled axial buckling of the hose after pressurization impacts the surrounding workspace, as well as (b) bunching, of either the outer or inner jackets. In the case of (b) – (c), the flow of working fluid can be severely restricted and greatly impact the performance of the product, requiring immediate maintenance work.

In order to perform a root-case analysis of the in-situ defects (excess length, snaking and bunching), it is necessary to conduct in-situ measurements during the operations. To this end, the hose was labeled during the operation at different locations through the length of the hose on the outer jacket (see Figure 3). The length of the lines were measured then before and after the operation to obtain the strains. Further, due to the movement of the fluid inside the tube and the pressure drop because of that, it is essential to measure the pressure drop along the hose.

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Figure 3. Marks on the outer jacket of the tube before the operation along the length and the circumference of the hose

Investigations of these measurements has led to increasingly valuable conclusions about the relation of the excessive lengths, and the root of it due the pressure drop. For such a complex system that cannot be fully and tractably modelled using finite element approaches, this experimental approach is necessary in understanding the nature and magnitude of the defects.

Results and Conclusions

The measurements were conducted on various hoses, over several days. The measurements reveal the behavior of the hose that has resulted in the defects such as bunching. The primary product of interest to the manufacturer is their line of 12” hoses with a TPU-liner on the inner jacket only, causing significant heterogeneity in the load response of the overall structure. Figure 4 shows the axial and circumferential mark lengths measures on the tested hose of this variety, from no-flow conditions to the maximum flowrate achievable of 6500 gallons per minute (GPM).

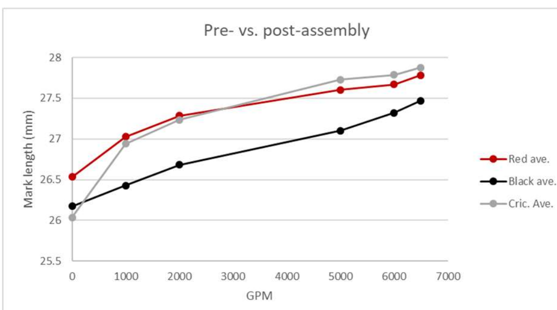

Figure 4. The recorded mark lengths along the 12” dual-jacket hose; axial – red (painted after assembly), axial – black (painted before assembly), circumferential - grey. The strain consistently develops higher as the flow rate and pressure of the fluid within also grows. This response is non-linear early on, but stabilizes at higher performance envelopes. Each point represents an average of measurements across the entire 430’ length of hose.

The load response of the 12” hose structures was largely linear, with a high degree of non-linearity early at lower loads/pressurizations. Further, other products (7.25” and 6.5”) were also tested in-situ. This data was also further subdivided to show a more local focus on the displacement data, with measurements made at four equally spaced regions along the hose; L1 (3’ from water inflow coupling), L2 (at 70’), L3 (at 140’) and L4 (3’ from water outflow coupling – 212’). This approach yielded more noise, given that fewer values were being averaged into single values. However, on average, there was overall a non-linear increase in the displacement of the hose, in-line with previous coupon-level testing.

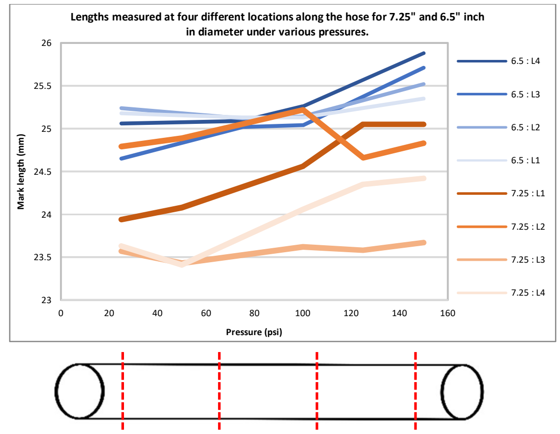

Figure 5. The length measurements at four different mark positions along the hose under various pressures for two hoses with 6.5” and 7.25” in diameter. Here, in addition to bring plotted as a function of water pressure, measurement zones were averaged (L1 – L4) for a more local view of displacements along the hose.

An experimental investigation into the in-service deformations of the industrial tubes performed and has been summarized. It is shown that samples tested depict the same patterns as in the lengths of the marked lines increases in the beginning of the hose where the flow enters the hose. On the other side, the opposite of the hose is under compression due to the axial load produced by the high-pressure flow.

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