# Ultrasonic Welded Straws for High Energy Physics Detectors

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**Abstract.** Straw tube detectors are widely used for High Energy Physics detectors such as NA62 experiment at CERN [1], aiming at studying rare kaon decays that play a major role in the development of the Standard Model. In order to minimise material budget for crossing particles and maintain transparency to the latter, the straws consist of thin wall rolled and welded tubes made from a Bidirectionally oriented Polyethylene Terephthalate (BoPET) film metallised with 50 nm of copper and 20 nm of gold. A successful production technology, based on ultrasonic (US) welding, has been developed for the 2.1 m long straws of NA62. These are operated since 2014 in a vacuum chamber with an internal pressure of 1 atm of a 70% Argon and 30% $CO_2$ gas. They have proven to be leak tight and dimensionally stable over the years. The wall thickness and diameter of the straws of the present experiment are 36 µm and 9.8 mm, respectively. A 30 µm gold-plated tungsten wire is strung in the centre of each straw. Future upgrades of straw detectors are envisaged for both high-intensity fixed target and beam dump experiments at CERN and elsewhere (such as SHiP [2], DUNE and COMET), that will enable precision measurements and search for new phenomena. Straws with thinner walls and smaller diameters will be needed to cope with higher particle rates and at the same time to further minimise the material budget (multiple scattering). The paper presents the outcome of the material and mechanical assessment of the US welding techniques deployed to create the new straws for the upgrade of the detector featuring an extremely thin wall and reduced diameter.

**Possible Sessions**

1. Adhesive and welded joints, 15. Nano & Micromechanical Testing, 26. Testing of Polymers

**Introduction.** The aim of a straw tracker is measuring with high accuracy the direction and momentum of charged particles. Each chamber of NA62 (Fig. 1) is equipped with 1792 straw tubes oriented in four different directions [3]. For the creation of the straw tubes of the future upgrades of NA62, BoPET has been selected for its proven transparency to radiations, limited gas permeation and weldability, namely by US welding, strength and isotropic characteristics. BoPET films are easy to metallise following a chemical treatment of the surface. For the future upgrades of the straw detectors, the material envisaged will be the same as for NA62 (BoPET inner coated with Cu and Au). However, in order to reduce further the material budget, the tube wall thickness will be decreased to 12 µm or 19 µm and the diameter of the straws to 4.82 mm. These changes imply production challenges, in particular to guarantee the soundness and tightness of the US welds with such reduced wall thickness.

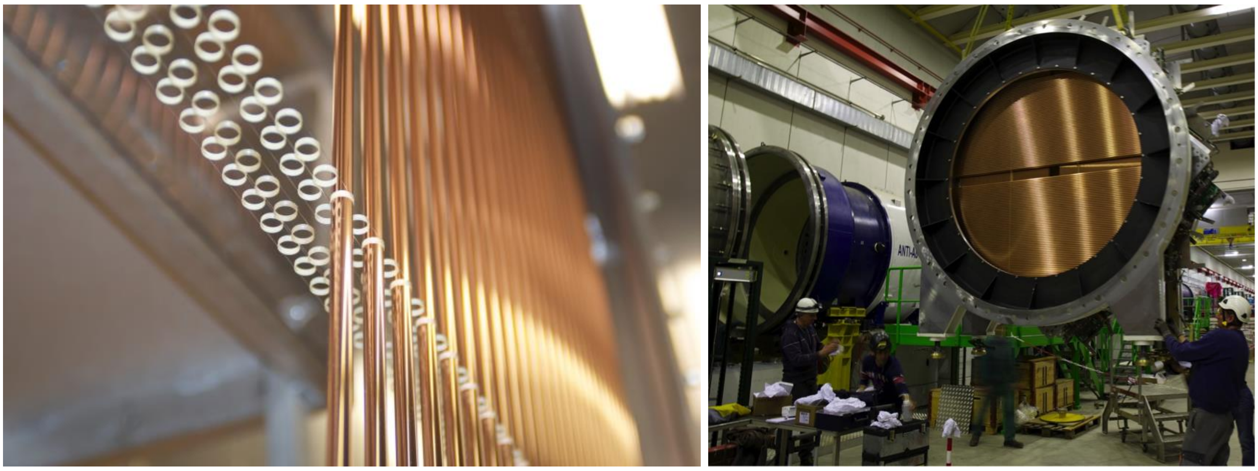
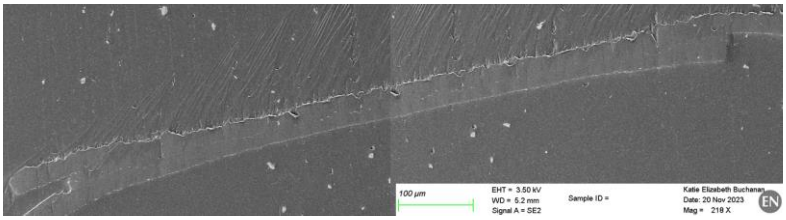


Figure 1 – Left: Straw tracker for the present NA62 experiment, based on straws manufactured from 36 µm thin BoPET foils coated with two Cu and Au. Right: The installation of one chamber in 2014 (Image CERN).

**Material and tests.** Wide rolls of 12 µm and 19 µm thick films of Hostaphan® GN 4600 BoPET provided by Mitsubishi Polymers, Cu (50 nm) + Au (20 nm) coated by the Fraunhofer Institute of Dresden in a roll-to-roll coater, have been splitted into spools matching the width to create the 4.82 mm diameter straws. Weld tests have been performed starting from the 19 µm film, rolled and US welded into tubes by the Swiss company SEFAR and the Joint Institute for Nuclear Research (JINR) in Dubna. Microstructural characterisation of the parent material and the welds have been performed at CERN with the help of a Keyence VHX-6000 Digital Microscope. Scanning Electron Microscope (SEM) and FIB-SEM observations were performed respectively with Zeiss Sigma and Sigma 500 Field Emission Gun (FEG) systems and a Zeiss XB540 FIB-SEM unit. Tensile tests have been carried out based on ISO 527 standard with the help of a Universal Testing Machine ZwickRoell AllroundLine Z010 (10 kN) equipped with an optical extensometer. Nanoindentation tests have been performed on a Step 700-UNHT3 Ultra nanoindenter unit from Anton Paar.

**Selected results.** The materialographic assessment of the welded joints (example in Fig. 2a) confirms a sound interface, with a bond density (proportion of projected bonded region to entire weld interface [4]) in the order of 90%, well within the 80% minimum project acceptance criteria. Moreover, the nanohardness measurements performed in the weld joint result in values comparable to the parent material, hence confirming a limited degradation (~20 % for the hardness and ~16 % for the nanoindentation elastic modulus E) of the local material properties following the welding operation (Fig. 2b-c). Tensile tests performed on the metallised parent metal and weld joints are reported in Table 1. Values for the parent material are close to the reported values for the uncoated Hostaphan® GN 4600 BoPET material. The higher elastic modulus is due to the contribution of the thin metal coating layers. For the 19 µm thickness, the weld joint efficiency (ratio of the joint and parent material transverse strength) is 41% for the SEFAR and 44% for the JINR joints, respectively. In spite of the thinner wall, the joint strength of the 19 µm straws (95.2 MPa and 101.6 MPa) is comparable, in absolute numbers, to the strength achieved in 2020 on the 36 µm thick straws (103.5 MPa).

a)




b)

| | Nanohardness – 1mN [MPa] | Nanohardness – 1mN [HV] | E [GPa] |
|---|---|---|---|
| Parent material | **292.2 ± 11.98** | **27.1 ± 1.24** | **6.89 ± 0.24** |
| Welded area | **236.6 ± 10.56** | **21.9 ± 1.09** | **5.77 ± 0.26** |

c)

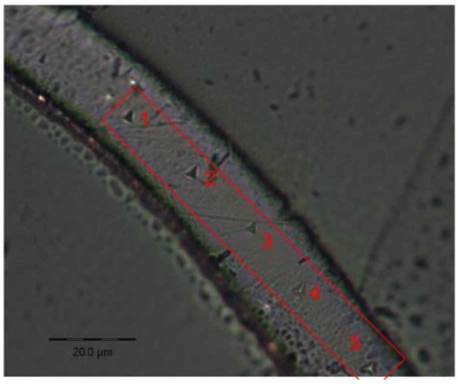



Figure 2 – a) SEM assessment of a JINR 19 µm US weld joint. b) Compared nanohardness values and nanoindentation elastic modulus (1 mN load) of the parent and weld material. c) Example of 1 × 5 nanoindentation array imaged by light microscopy.

| | Stress at break [MPa] | Strain at break [%] | Stress at 5% of strain [MPa] | Force at break per unit length [N/mm] | Elastic modulus [GPa] |
|---|---|---|---|---|---|
| **Transverse - 12 µm** | 229 ± 2.5 | 62 ± 17.1 | 105 ± 2.2 | 2.86 ± 0.03 | 5.7 ± 0.08 |
| **Transverse - 19 µm** | **232 ± 8.9** | 65 ± 3.5 | 105 ± 1.8 | **4.66 ± 0.10** | 5.8 ± 0.60 |
| **Longitudinal - 12 µm** | 231 ± 10.0 | 94 ± 5.2 | 110 ± 0.8 | 2.93 ± 0.13 | 5.13 ± 0.15 |
| **Longitudinal - 19 µm** | 252 ± 6.0 | 110 ± 2.6 | 110 ± 0.9 | **5.06 ± 0.07** | 5.22 ± 0.08 |
| ***Transverse – 36 µm*** | *184.7 ± 6.9* | - | - | - | - |
| ***Hostaphan ref. (12-23 µm thick)*** | *260* | *120* | *110* | - | *4.40* |
| **US joint (SEFAR) - 19 µm** | **95.15 ± 6.60** | - | - | **1.81 ± 0.13** | - |
| **US joint (JINR) - 19 µm** | **101.6 ± 20.8** | - | - | **2.05 ± 1.11** | - |
| ***US joint (JINR - 2014) 36 µm*** | *103.5 ± 0.9* | - | - | *3.6 ± 0.14* | - |

Table 1 - Tensile properties of the 12 µm and 19 µm parent materials (blue rows - including, for reference, the stress at break of the 36 µm product installed in 2014) and (yellow rows) of the US joints (19 µm and for reference, 36 µm wall thickness straws). The weldability of the 12 µm product is still to be proven.

**Conclusion.** The feasibility of US welded thin wall straws has been demonstrated on a 19 µm product by two different suppliers, featuring an outstanding weld soundness, a joint ultimate strength close to the one of the thicker straws used in the present NA62 experiment and local properties of the weld not too far from the ones of the parent material. Further assessment of prototype straws and first of series products will be applied to confirm the reliability of the products for application to future upgrades of the detector. The feasibility of 12 µm straws will be also explored.

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## References

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