Measurement of Flux Mass in Flux-Cored Welding Wires by Two Methods

Samson Nellickappillil, Makarand Rele, Daniele Calista, Patricio F. Mendez

Background and objectives

- Flux-Cored Arc Welding is widely used in structural fabrication, including construction, shipbuilding, and heavy-equipment repair, where its high deposition rate is an advantage.
- Unlike solid wire, flux-cored wire is a composite consumable consisting of an outer steel sheath and a powdered flux core. The sheath supplies weld metal, while the core supports shielding, slag formation, arc stabilization, and deoxidation
- Welding mass and energy balances require the flux mass fraction to support calculations of consumable melting, droplet temperature, deposition efficiency, and arc efficiency.
- Manufacturers generally do not report this value. Irregular core geometry and internal voids also make it difficult to determine reliably from cross-sectional geometry alone.

OBJECTIVE 1: Quantify the flux content of a commercial flux-cored wire, as mass per unit length, and mass fraction, with valid uncertainty

OBJECTIVE 2: Compare direct mass measurement and cross-section projection based on variability to identify the preferred method

Materials

Table 1 – Wire Specification

Wire	Lincoln Electric Innershield NR-232
Classification	AWS E71T-8
Diameter	1.8 mm
Process	Self-shielded FCAW

Direct Measurement Equipment
Wire cutter • Caliper • Pliers • Hand Drill • Compressed Air • Digital Balance

Geometric Imaging Equipment
Wire cutter • Caliper • Digital Balance • 180-grit Sandpaper • Keyence Microscope • ImageJ

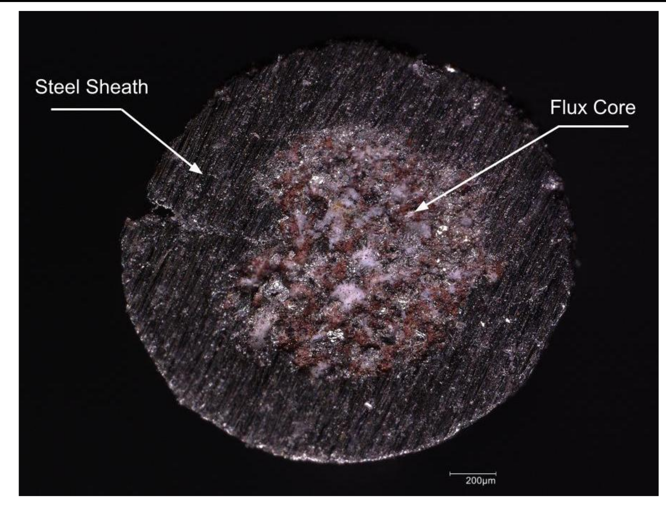

Fig. 1 – Flux-Cored Wire Cross Section

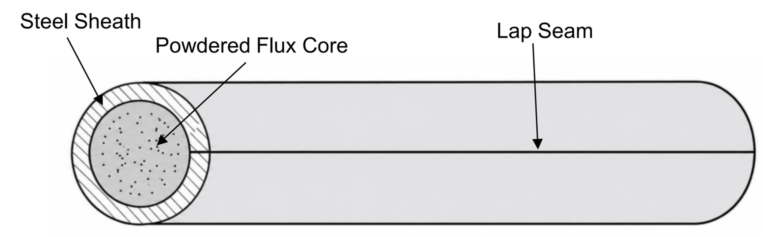

Fig. 2 – Schematic of flux-cored wire

Method 1: Direct Measurement

Principle: Direct Measurement removes the powder core and calculates its mass from the difference between the intact wire and emptied sheath.

Specimens
n = 29, L≈ 38 mm

Assumptions
- All mass loss is attributed to removed flux
- No steel is lost during opening or cleaning

1. **Section and Weigh**
   - Cut samples; record total mass, m_{total} and sample length, L
2. **Open Wire Sheath**
   - Unwind wire using pliers and hand drill
   - Slow rotation opens lap seam without cutting
3. **Extract Flux**
   - Clean opened sheath with compressed air and cloth, until no powder is visible
4. **Reweigh and Calculate**
   - Measure steel mass; calculate flux mass by difference

Fig. 3 – Wire sheath opened using pliers and drill rotation

Fig. 4 – Wire sheath (a) before and (b) after flux removal

Flux Content, Measured

$$m_{\text{flux}} = m_{\text{total}} - m_{\text{steel}}$$

$$\lambda_{\text{flux}} = \frac{m_{\text{flux}}}{L} \qquad f_m = \frac{m_{\text{flux}}}{m_{\text{total}}}$$

All required masses are measured directly; no cross-sectional geometry density, or packing factor enters the calculation. Main risks are incomplete flux removal and steel loss during opening.

Method 2: Cross-Section Projection

Principle: Cross-section projection estimates flux mass by converting the traced steel area to mass and subtracting it from the total mass.

Specimens
n = 30, L ≈ 38 mm

Assumptions
- Steel density is constant at $7.85\ \text{gcm}^{-3}$
- Nominal wire diameter is 1.8 mm

1. **Section, Grind, Weigh**
   - Cut samples and grind both faces flat; record total mass, m_{total} and sample length, L
2. **Image Both Faces**
   - Image both faces using stereomicroscopy
   - Both faces are analyzed independently, then averaged
3. **Trace Surface Boundaries**
   - Trace outer-wire and inner-core boundaries in ImageJ
4. **Convert Area to Mass**
   - Project mean steel area through length; calculate steel and flux mass

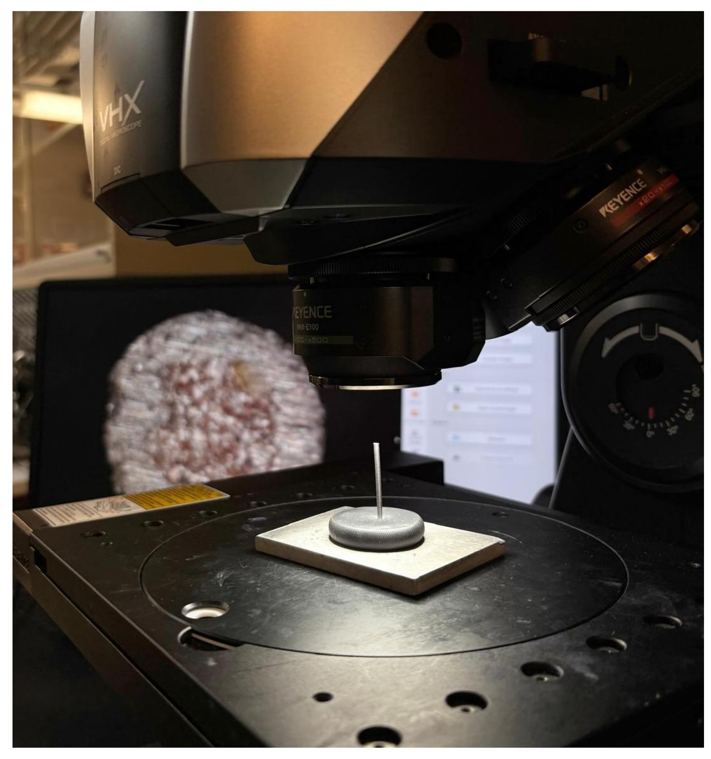

Fig. 5 – Wire sample positioned under Keyence microscope for cross-sectional imaging

Flux Content, Estimated

$$m_{\text{steel}} = \rho_{\text{steel}} A_{\text{steel}} L$$

$$m_{\text{flux}} = m_{\text{total}} - m_{\text{steel}}$$

λ_{flux} and f_m follow as in direct measurement

Flux mass is calculated by difference; no powder packing factor is needed. Steel mass is inferred from projected area and density, making the result sensitive to section preparation and boundary tracing

Results and Discussion

Table 2 – Method statistics

Statistics	Direct Measurement	Cross-Section Projection
Samples, n	29	30
Mean Flux Mass Fraction	18.35	11.49
Standard Deviation of Flux Mass Fraction (%)	0.57	2.15
Mean Flux Mass per Unit Length (g/m)	2.60	1.63
Standard Deviation of Flux Mass per Unit Length (g/m)	0.09	0.30

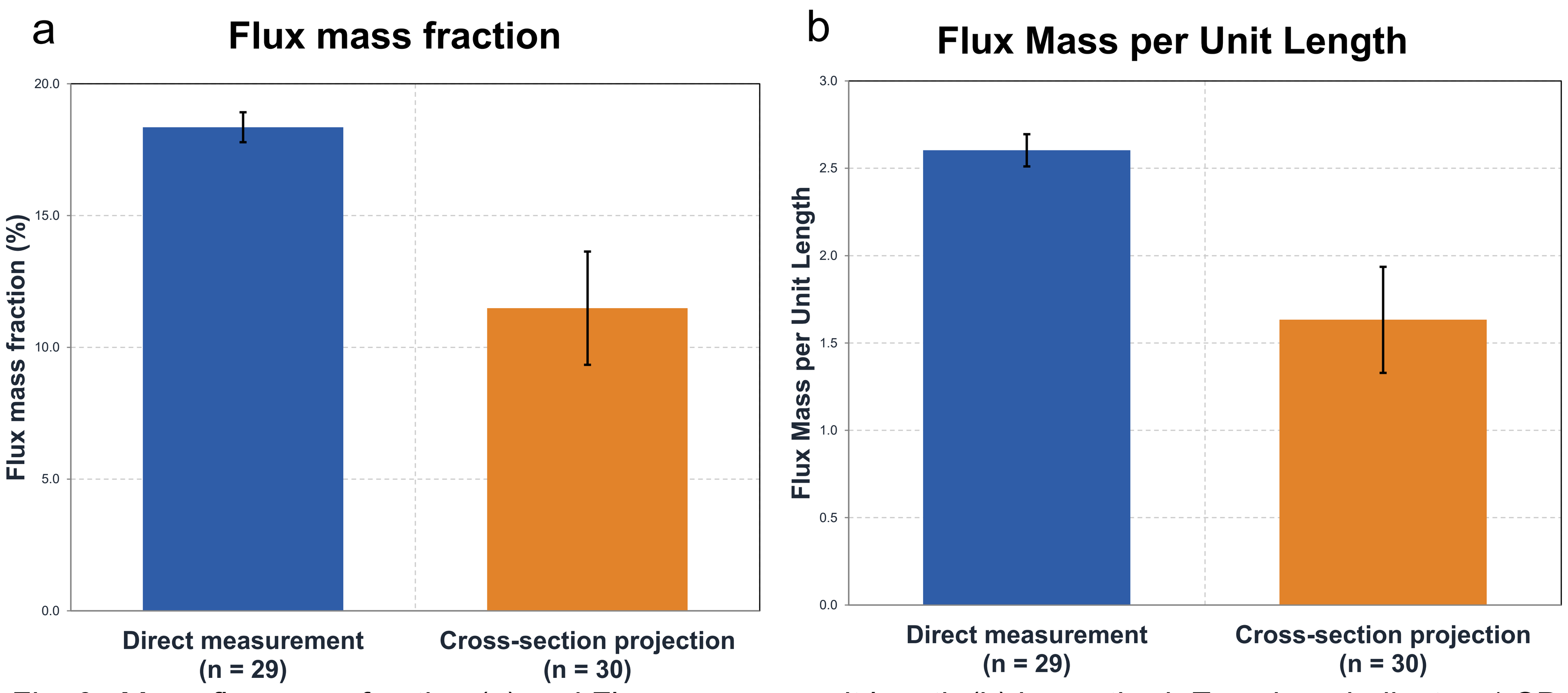

Fig. 6 - Mean flux mass fraction (a) and Flux mass per unit length (b) by method. Error bars indicate ±1 SD

Method Comparison

- Measurement variability was characterized using the sample standard deviation (SD)
- Direct measurement showed lower variability for both flux mass fraction (SD = 0.57 vs. 2.15 %) and flux mass per unit length (SD = 0.09 vs. 0.30 gm^{-1}).
- Cross-section projection produced mean values approximately one third (37%) lower than direct measurement

Potential Sources of Bias in Cross-Section Projection

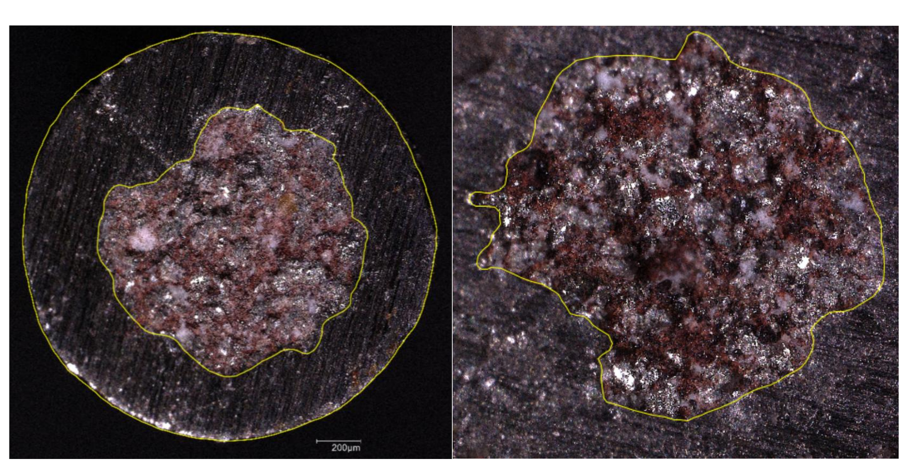

Fig. 7 – Irregular traced boundaries complicate the area-based mass estimation

- The mean traced outer area was $2.70\ \text{mm}^2$, approximately 6% above the nominal area of $2.54\ \text{mm}^2$
- Grinding can dislodge flux and produce irregular boundaries that complicate tracing
- Changes in crimp and core geometry limit the constant-area assumption

Method Assessment

- Overestimating the steel area increases the estimated steel mass and lowers the calculated flux mass.
- SD captures sample-to-sample variability but not potential bias from sample preparation, boundary tracing, assumed steel density, or changes along the wire
- Direct measurement produced lower variability and requires fewer assumptions, making it the preferred quantitative method.

Conclusions and Future Work

- Flux mass was determined using two methods: direct measurement and cross-section projection; both methods determined flux content without requiring powder packing factor
- Direct measurement gave a flux mass fraction of 18.35 ± 0.57 % (2.60 ± 0.09 g/m), while cross-section projection gave 11.49 ± 2.15 % (1.63 ± 0.30 g/m); uncertainties are ± 1 SD
- Direct measurement is preferred as it showed lower variability and requires fewer assumptions
- Future work will apply the measured steel-to-flux mass ratio to FCAW mass and energy balances and extend direct measurements to additional wires and spools.

Acknowledgements

The authors acknowledge Dr. Ivan Pigozzo, Dr. Xinrui Liu, Nitheesh Kumar, and Mia Abdulla for their guidance, mentorship, and continued support

Welding wire supplied by LINCOLN ELECTRIC