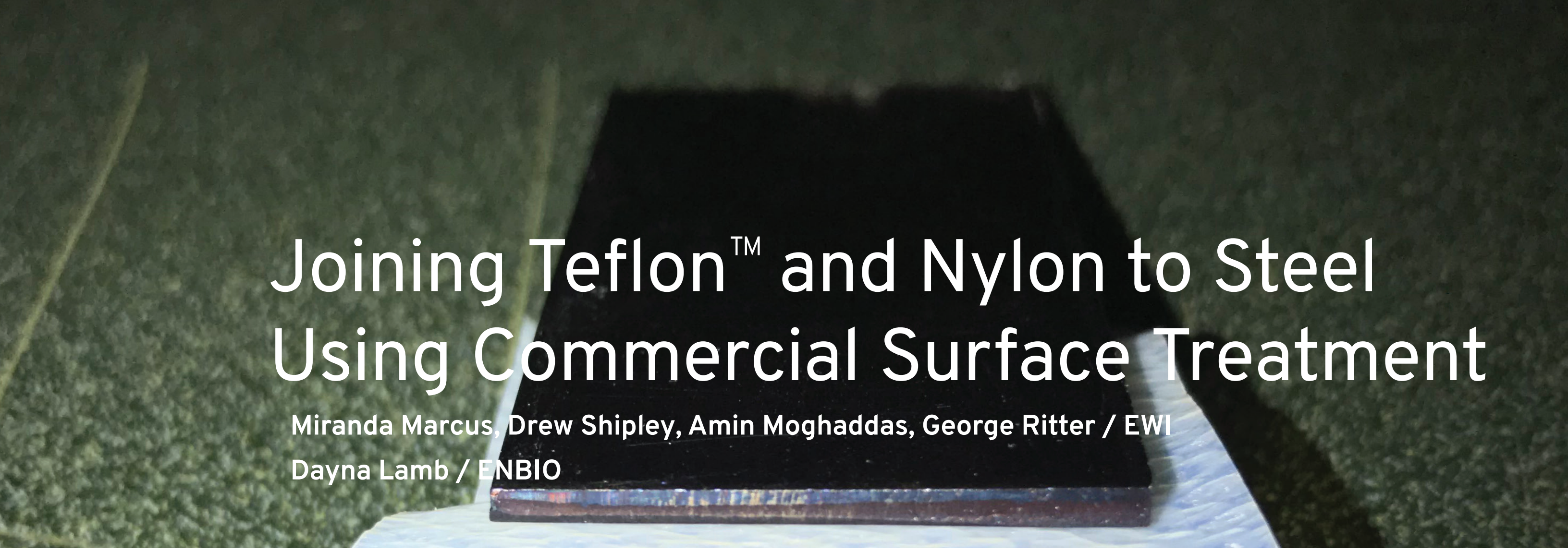

Joining Teflon™ and Nylon to Steel Using Commercial Surface Treatment

Miranda Marcus, Drew Shipley, Amin Moghaddas, George Ritter / EWI
Dayna Lamb / ENBIO

Bonding of polymers to metals is important to many applications which benefit from the material properties of both. Below are common example applications in which direct polymer-to-metal joining offers distinct benefits:

BATTERIES

- *Direct joining can allow smaller packages*
- *Bonds without consumables reduce costs*
- *Avoids the difficulty of finding adhesives that can withstand the electrolyte environment*

AUTOMOTIVE

- *Avoids excess weight from adhesives and mechanical fasteners*
- *Direct joining improves fuel efficiency form light-weighting*

MEDICAL DEVICES

- *Better quality joints -- many medical grade plastics (fluoropolymers, some polyolefins) are difficult to bond with medical grade adhesives*

Recently, EWI investigated a method of direct joining using a commercially available surface treatment, CoBlast, developed by ENBIO Ltd. CoBlast is a proprietary surface modification in which the metallic surface is simultaneously bombarded with an abrasive medium and a coating material (dopant). In this one-step process, the abrasive removes the oxide layer and roughens the surface, allowing the dopant to form an enhanced bond, as shown in Figure 1.

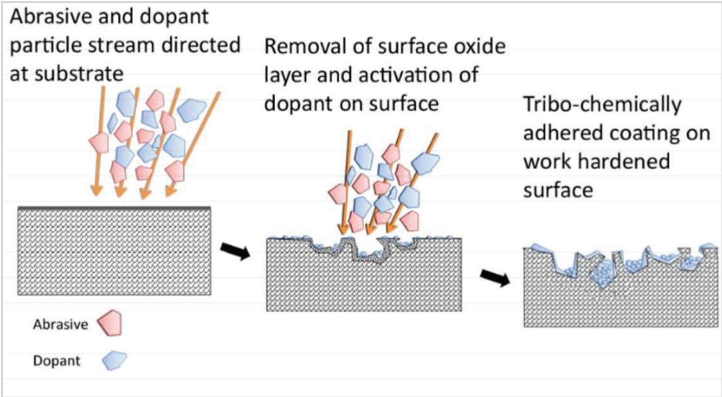

Figure 1. Diagram of CoBlast Process

Materials

Table 1 shows the combinations of materials for which joining was attempted. Note that "blasted" refers to the case where the CoBlast process was completed, but without using a dopant, simply to create a roughened surface.

Table 1. Material combinations trialed

Treatment Type	Film Material
PTFE-CoBlast	PTFE
PFA-CoBlast	PTFE
FEP-CoBlast	PTFE
Hydroxyapatite CoBlast	PA
Blasted (no dopant)	PTFE/PA
Untreated	PTFE/PA

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The surface treatments were applied to 1.90 mm thick, cold-worked, low-carbon steel. The polytetrafluoroethylene (PTFE, Teflon) film was 0.30 mm thick. Two thicknesses of polyamide (PA, nylon) film were used, 0.05 mm and 0.80 mm.

Several fluoropolymer type surface treatments were selected to try to bond to the Teflon film. To bond the nylon film, it was anticipated that because PA is similar to protein and the hydroxyapatite is similar to bone, that some bonding may be able to be promoted between the two.

Fourier transform infrared spectroscopy (FTIR) analysis was performed on each of the treated surfaces and the film materials. The results for the fluoro treatments and PTFE film are shown in Figure 2. These spectroscopy graphs confirm the significant presence of carbon-fluorine bonds in all the fluoro polymers and the PTFE film, which was as expected. This analysis was performed simply to provide qualitative confirmation of the presence of the expected bonds.

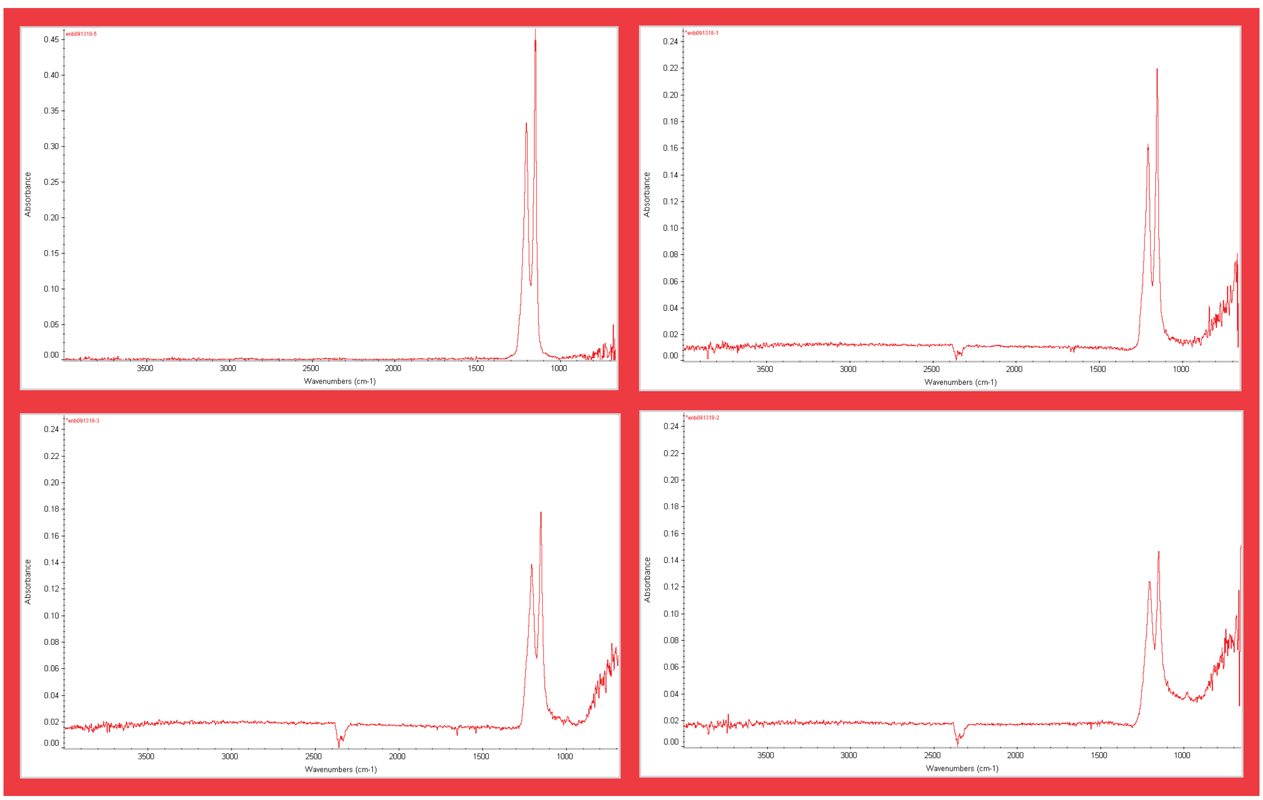

Figure 2. FTIR results for PTFE film, PTFE CoBlasted metal, PFA CoBlasted metal, and FEP CoBlasted metal (clockwise from top left)

The surface energy of the various joined materials was also measured (Figure 3). Unsurprisingly, the fluoropolymer surface treatments showed very low surface energy, as these treatments are typically used to reduce friction and prevent sticking. In comparison, the hydroxyapatite coating had a high surface energy.

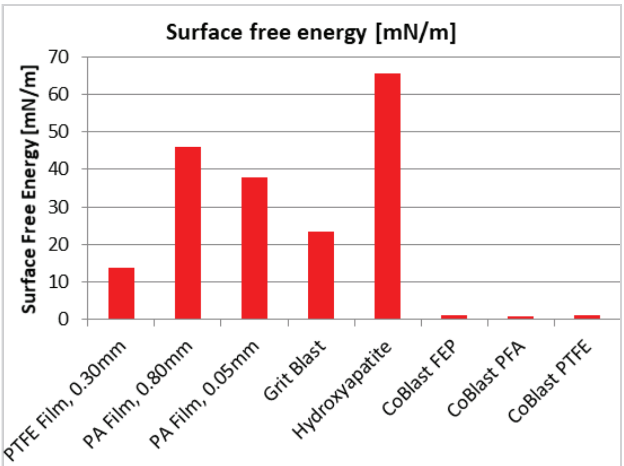

Figure 3. Surface energy of the materials, before bonding

Equipment

Two joining methods were explored. In the first case, a thermal staking press was utilized to apply heat and pressure. Then, the metal coupons were placed on a hot plate to preheat before joining. This is referred to as the "two-sided" process as heat was applied from both sides and the film was sandwiched between two metal coupons.

Additional work was done using a pneumatic ultrasonic press to apply pressure and a hot plate to heat the metal samples via direct contact. The samples were placed on the hot plate until they reached the set temperature. The film was adhered to the upper tool and heated for the listed "preheat" time in close proximity to the hot plate, via non-contact radiant heating. This is referred to as the "one-sided" process.

The setups for these two joining processes are shown in Figure 4.

Figure 4. Joining approaches used

Two-sided Process

For the two-sided process, the joining parameters shown in Table 2 were used. The parts were preheated to the lower temperature, and the upper temperature was applied only during the joining time.

Table 2. Two-sided process joining parameters

Film Type	Lower Temp (C)	Upper Temp (C)	Pre-Heat (sec)	Joining Time (sec)	Force (Kg)
PTFE	246	520	240	240	20-30
PA (thick)	213	520	90	75	20-30

After shear testing, the bond area was estimated using ruler measurements and visual assessment of the fracture surface (shown in Figure 5).

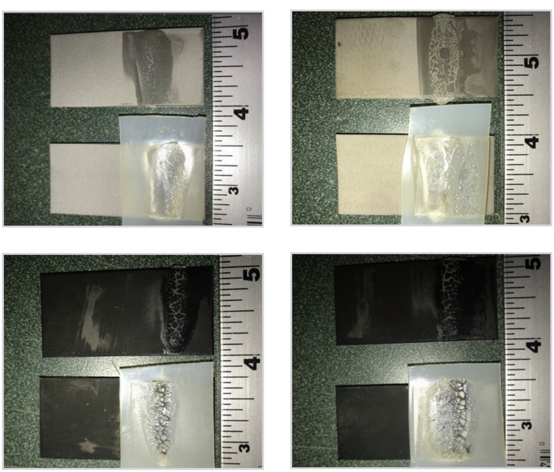

Figure 5. Fracture surface of PA film joints made with two-sided process, top row shows blast surface, bottom row shows calcium phosphate surface treatment

Figures 6 and 7 show the strength results for the PTFE film and PA film joining trials for each surface treatment method. Ultrasonic welding using the ultrasonic wire bonder was also able to produce welds using the 0.0007" copper.

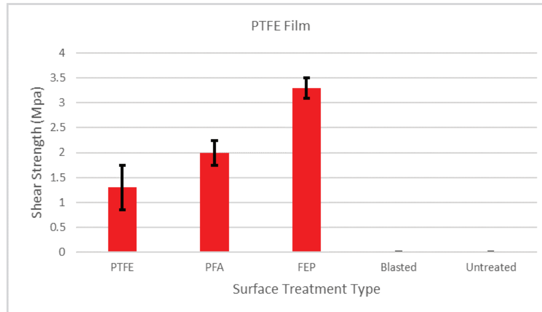

Figure 6. Strength of bond for PTFE films using two-sided process

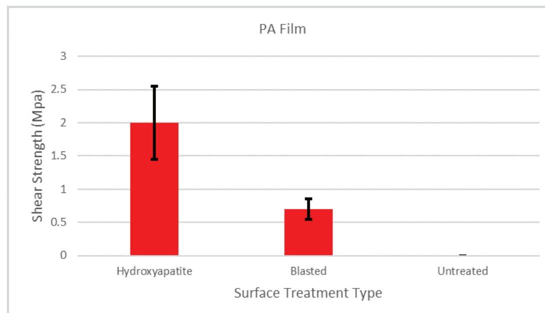

Figure 7. Strength of bond for PA films using two-sided process

The two-sided process did not result in any bonding of the film to the untreated steel, nor could it produce a bond of the PTFE film to the blasted steel. The FEP coating provided the greatest increase in bond strength for the PTFE to steel trials. Direct temperature measurements at the bond interface were not made during this trial, however it is theorized that FEP worked the best in this application due to the it's lower melting temperature which would allow improved flow.

The PA material could be joined with the blasted steel, although the bond strength was less than what was achieved with the calcium phosphate coating. This demonstrated that the coating did improve the bond performance.

Several assemblies failed at the coating-to-steel surface, rather than at the polymer-to-coating surface, as shown in Figure 8.

Figure 8. Coating to steel failure shows strength of bond between calcium phosphate and PA.

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One-sided Process

The one-sided process used an unheated upper tool. In this case, the film was pressed directly into the metal coupon, which was heated to a pre-determined temperature on a hot plate. With this setup, the joining parameters shown in Table 3 were used.

Table 3. One-sided process joining parameters

Film Type	Metal Temp (C)	Film Pre-heat Time (sec)	Joining Time (sec)	Force (Kg)
PTFE	380	20	120	64
PA (thin)	250	15	20	64

Using this process to bond the thinner PA film to the blasted steel coupon produced a strong enough bond that the failure occurred in the parent material for every test. Therefore, there is no Mpa strength data for this combination, because a bond area could not be measured. When the calcium phosphate coating was used, one of the five samples also resulted in a base material failure. An example of the failure mode is shown in Figure 9.

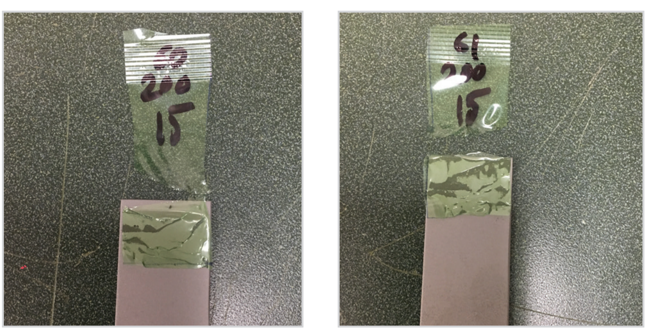

Figure 9. Failure mode for bonding of thinner PA to blasted steel, and one of the bonds to the hydroxyapatite coating

None of the fluoropolymer bonds failed in the parent material, however, so the strength in terms of MPa could be found (Figure 10).

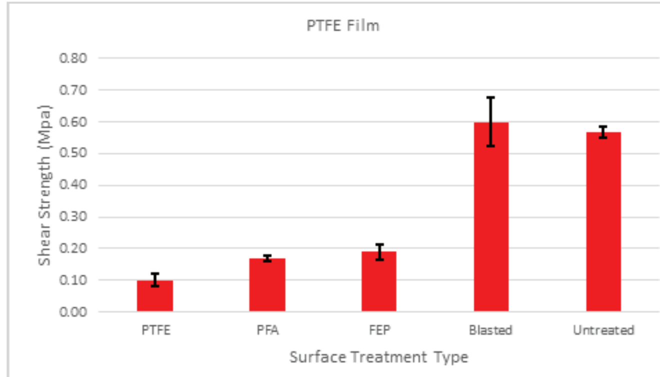

Figure 10. Strength of bond for PTFE films using one-sided process

It is possible that by heating the metal coupon to a set temperature, rather than heating for a shorter duration, the fluoro-coatings were damaged, which might have caused the reduced bond strengths for these samples. Regardless, even with this one-sided setup, the FEP was the strongest of the coatings used for the PTFE trials.

The ability to get a bond on the PTFE to the untreated steel, even without a blast treatment is of particular note. However, it is possible that hydrofluoric acid was produced due to the decomposition of the PTFE at high temperature, etched the steel, and permitted mechanical interlocking of the polymer into the steel surface.

Conclusions

These trials demonstrated that the ENBIO CoBlast surface treatment method can be used to improve the strength of direct bonding between PTFE and steel and between PA and steel. Particularly, the FEP coating provided significant improvement in strength with the two-sided joining process to a PTFE material, giving a 250% increase in strength in comparison to using a PTFE coating.

The longer heating times used in the one-sided process significantly improved bonding to steel when either untreated, or when CoBlasted with no dopant.

To learn more about Joining Teflon™ and nylon to steel using commercial surface treatment email Miranda Marcus at **mmarcus@ewi.org**.

Miranda Marcus, *Applications Engineer, is EWI's technical lead for plastic and composite welding technologies. She has extensive knowledge of plastic welding techniques including ultrasonics, laser, spin, hotplate, vibration thermal staking, radio frequency, and infrared.*

Drew Shipley, *Project Engineer, is a member of EWI's materials engineering team. He is involved in developing and optimizing the bonding of similar and dissimilar materials using EWI lab furnaces and also works with solid-state bonding technologies.*

Amin Moghaddas, PhD, *is a Project Engineer in the EWI ultrasonics group. He specializes in research and development of ultrasonic-assisted drilling (UAD) and has developed several techniques for measuring temperature and vibration amplitude in UAD.*

George W. Ritter *is a Principal Engineer with specialty in adhesives bonding systems and processes. His work includes adhesives applications for metals and plastics in automotive, aerospace, marine, general industrial, electronics, and medical fields.*

Dayna Lamb *is the former VP of Sustainability & Regulatory Compliance for ENBIO Ltd.*