# Wind Uplift Rating of TPO Systems:

# NEW DATA CONFIRM THE THEORY OF DOUBLE-SIDE WELD TECHNOLOGY

By A. Baskaran and G. Xu

Thermoplastic polyolefin (TPO) membranes, members of the thermoplastics family, are positioning themselves well among the new generation of single-plies. TPOs may be produced either by a reactor process using a specific catalyst or from a physical blend of the olefin phase and an ethylene propylene rubber. Polyester scrim has been primarily used as the reinforcement in these membranes. Relatively new to the North American roofing market, TPOs claim excellence in UV and tear resistance. Hot air welding characteristics are also an advantage for rooftop applications of these membranes. The weathering resistance of the membrane is mainly derived from the presence of the ethylene propylene rubber, while the olefin phase imparts chemical resistance, tear resistance, and hot air weldability.

Roofing systems are subjected to various levels of wind dynamics during their lifetime. The wind forces cause the membrane to lift and billow, introducing stresses on the attachment locations (*Figure 1*). The attachment locations are overlapped as seams to maintain water tightness of the roof. In a roof assembly with TPO membranes, the seams are created by one-side weld or traditional seaming methods. Conventionally, seams have an overlap of 127 mm (5 in), with the fastener placed 38 mm (1.5 in) from the edge of the under sheet, and 89 mm (3.5 in) from the edge of the overlapping sheet. The portion of the seam beyond the fastener row can be welded with hot air such that a waterproof top surface is obtained. The width of the welded portion varies between 38 and 45 mm (1.5 and 1.75 in).

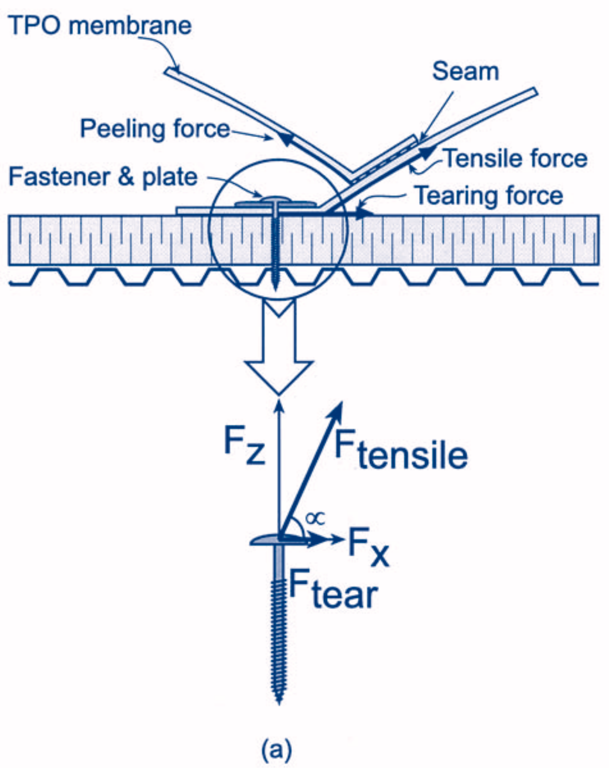


*Figure 1(a). TPO roofing systems subjected to wind uplift; one-sided weld configuration.*

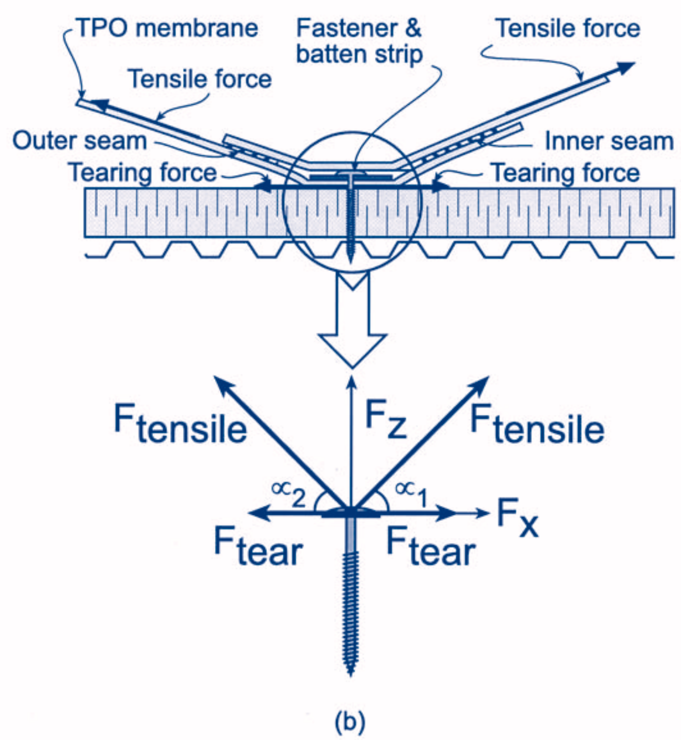


*Figure 1(b). TPO roofing systems subjected to wind uplift; double-sided weld configuration.*

Advancements in welding technology have led to double-side weld procedures[1] or encapsulated seams. Double-side welding is used primarily in conjunction with metal or plastic batten strips. The strip, usually 25 mm (1 in) wide, is centered inside a 100 mm to 127 mm (4 in to 5 in) lap seam. A double-nozzle, hot air robotic machine (*Figure* 2) is used to create an approximate 32 mm (1-1/4 in) weld on either side of the strip. The welding quality mainly depends on the selection of the welding parameters, which include temperature, speed, and compacting pressure (weight).

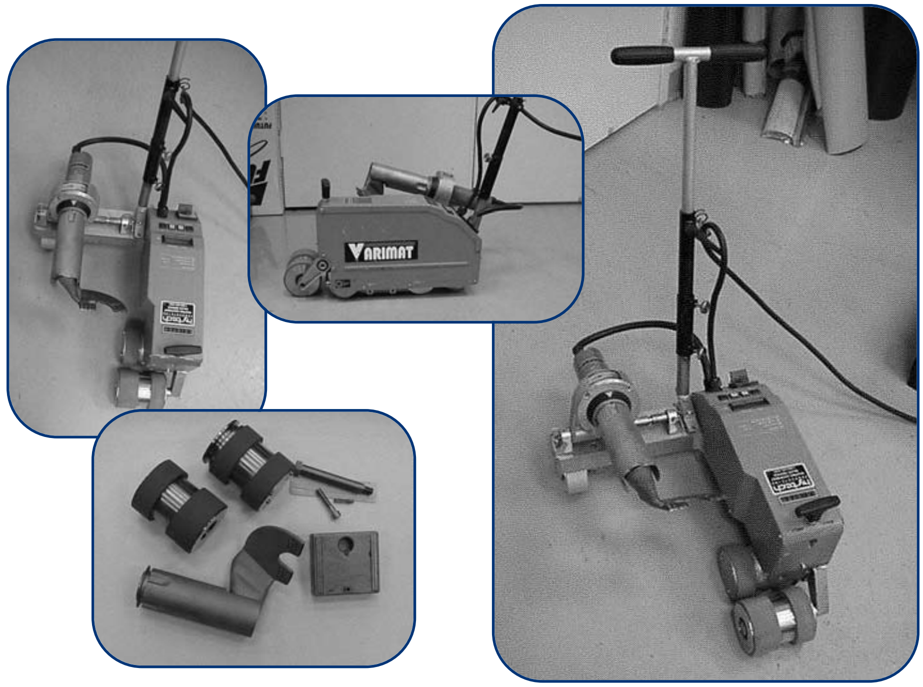


*Figure 2. Hot air welding machine with double weld technology.*

## The Theory

*Figure 1* shows a simplified force diagram for the TPO systems with one- and double-sided welds. In one-sided weld systems, tensile and tear forces are introduced along the direction of the weld. With a weld on each side of the fastener, tensile and tear forces are developed along the two opposite directions of the welds. In theory, they can be expressed as follows:

**Systems with one side weld:**

$$F_x = F_{tear} + F_{tensile} \bullet \cos \alpha \qquad (1)$$

$$F_z = F_{tensile} \sin \alpha \qquad (2)$$

**Systems with double side weld:**

$$F_x = F_{tear} + F_{tensile} \cos \alpha_1 - F_{tensile} \cos \alpha_2 - F_{tear} \qquad (3)$$

$$F_z = F_{tensile} \bullet \sin \alpha_1 + F_{tensile} \bullet \sin \alpha_2 \qquad (4)$$

Where: $F_x$ and $F_z$ are the respective horizontal and vertical forces and $\alpha$, $\alpha_1$ and $\alpha_2$ are the membrane orientation angles due to wind uplift.

It is evident from equation (3) that part of the forces developed on the fastener in the horizontal direction for the double-sided welded system can cancel each other due to their quasi-symmetrical stress distribution pattern. On the other hand, the stress distribution is asymmetrical in the one-sided welded system. This would imply that the induced load along the horizontal direction would be higher for the one-sided weld system than the double-sided welded system. Consequently, the degree of fastener being rocked sideways and causing membrane tearing would be reduced when using double-welding technology. This can facilitate the transfer of the majority of the wind uplift forces directly to the deck. Data from a recent experimental investigation confirmed this theory.

## Dynamic Wind Test Protocol

Wind rating tests were conducted in the Dynamic Roofing Facility (DRF)[2] of the National Research Council of Canada, using the SIGDERS (Special Interest Group on Dynamic Evaluation of Roofing Systems) dynamic wind test protocol.[3] As shown in *Figure 3*, the SIGDERS dynamic protocol has five rating levels (A to E). To evaluate a roof assembly for a specific wind resistance, all the gusts corresponding to Level A should be

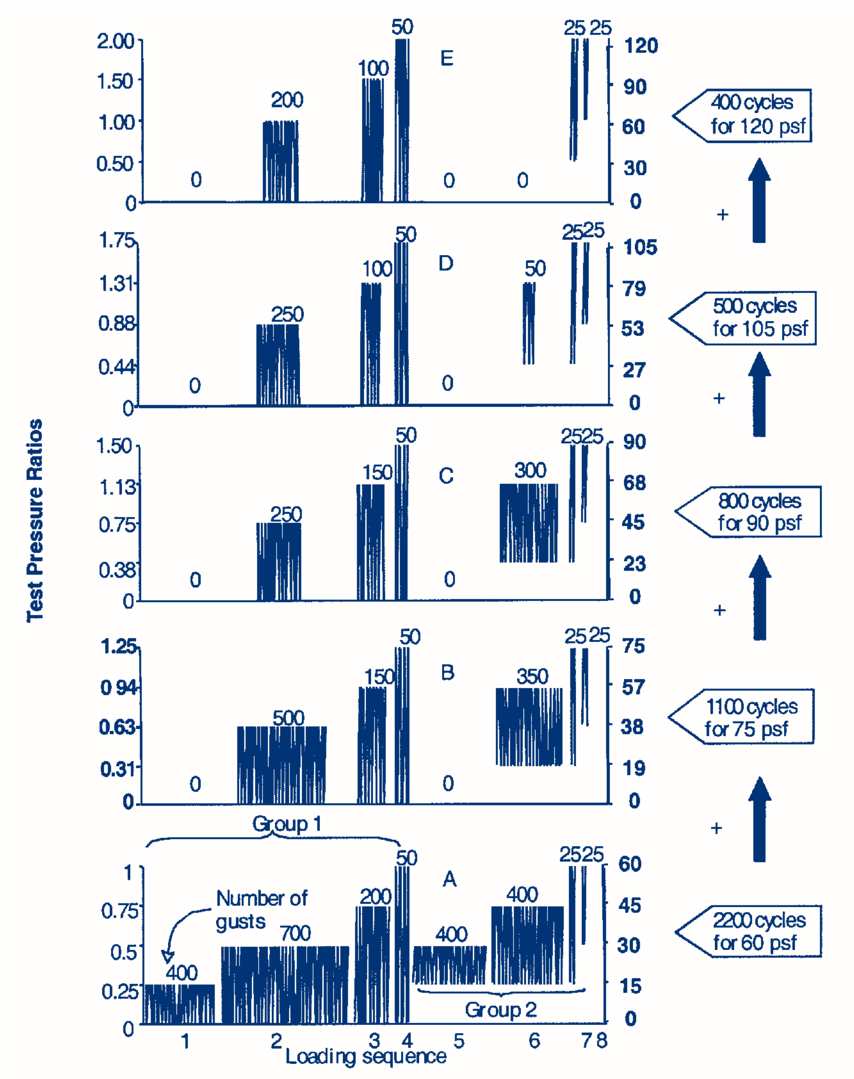


*Figure 3. SIGDERS dynamic wind test protocol.*

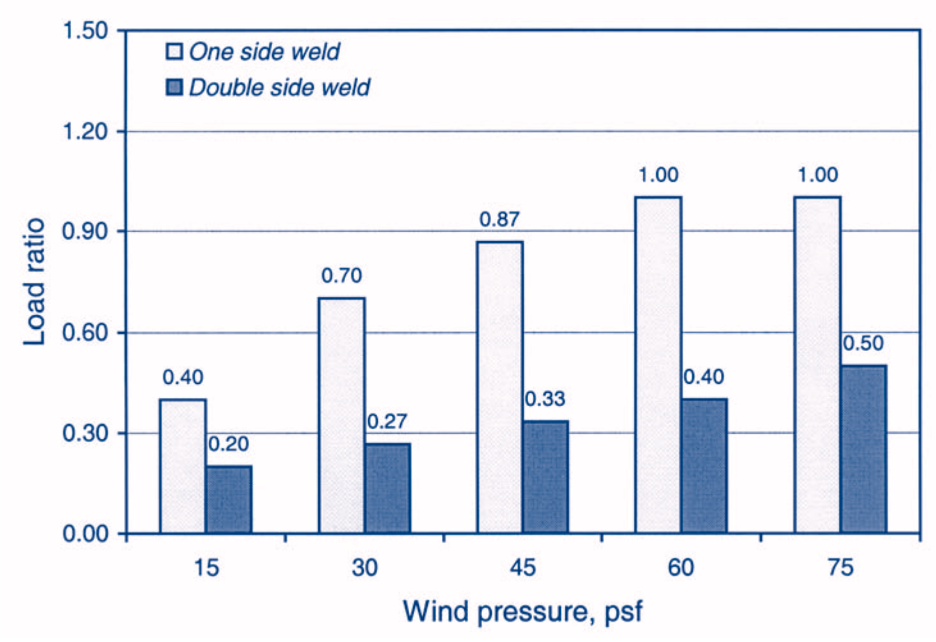


*Figure 4. Comparisons of fastener load at x direction via wind uplift pressure between one-sided weld and double-sided weld TPO roofing systems.*

applied. To evaluate the ultimate strength of the roofing system, testing should be started at Level A and be incremental and continuous when moving from one level to another. To obtain a rating, all specified numbers of gusts in each level must be completed. For the present investigation, all the tests started from Level A with maximum pressure of 60 psf.

## System Response

### Wind Uplift Rating

Systems with 75-inch reinforced TPO sheets are fastened at 12 inches on center over 4' by 8' ISO boards with steel deck. Systems tested with the one-sided weld sustained a wind pressure of 60 psf and failed at 75 psf. The double-sided welded assemblies sustained 90 psf and failed at 105 psf. Having the same fastener density, the systems with double-sided welds yielded higher wind uplift ratings than the systems with one-sided weld.

### Measured Fastener Load

Wind-induced fastener forces were measured using a load cell specially developed by NRC. Both horizontal- and vertical-force components were measured. For the horizontal component, graphical comparisons between the two systems are shown in *Figure 4*. They are presented as load ratios at different pressures. These ratios are obtained by dividing measured load at each loading sequence with the maximum measured load from the one-sided welded system. The data indicate that the horizontal forces were reduced by about 50% due to the double-sided welding technology. This is due to the load transfer mechanism of the batten strip in the double-sided welded systems as explained below.

### Failure Mode

The stress distribution along the mechanically-fastened seams is different between the two systems when wind influences are applied. In the double-sided welded systems, the batten strips can spread the wind uplift along the length of the seam rather than localizing it at the fasteners or in the membrane around the vicinity of the fastener plates. On the other hand, in a one-sided welded system, the stress localization causes either an early fastener pullout if the membrane is strong enough, or membrane tearing around the plates. The latter was the failure mode observed during the test of the one-sided welded systems at NRC (*Figure 5*).

## Conclusions

Use of double-sided weld can minimize stress concentration, and it can promote the wind rating of the mechanically-attached TPO roofing systems. Most of the induced load is directly transferred to the structural deck. ■

## Acknowledgments

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## References

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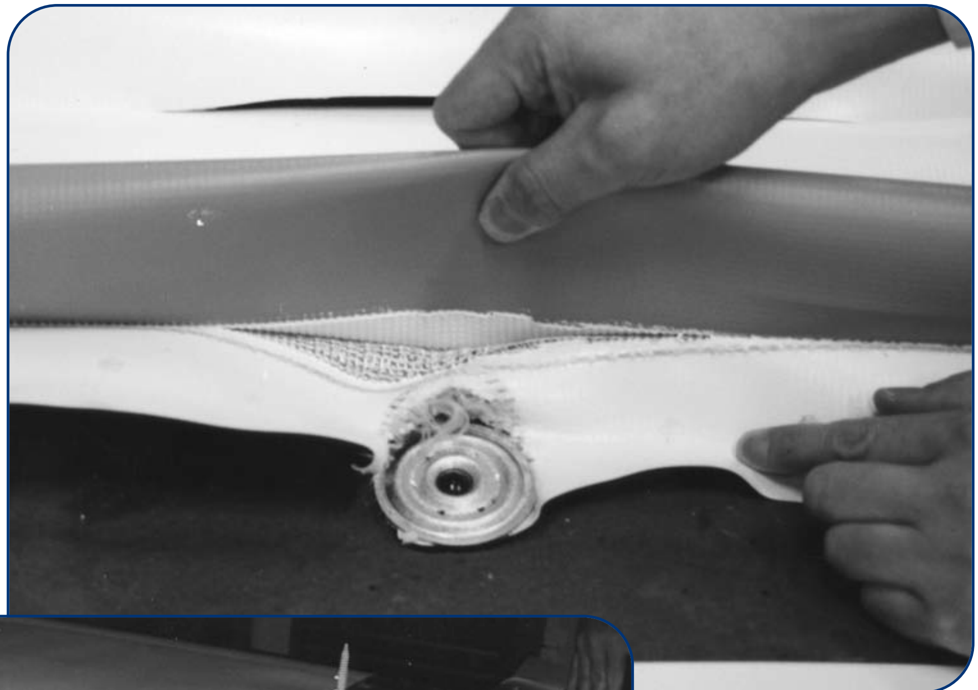

*Figure 5. Failure modes of mechanically-attached TPO roofing systems after dynamic testing. Top photo: Membrane tearing failure mode of the system with one-sided weld. Bottom photo: Fasteners pullout failure mode of the system with double-sided weld.*

## About the Authors

**Dr. A Baskaran**

**Dr. Baskaran** is a Group Leader for the Roofing Sub-Program at the National Research Council of Canada, Institute for Research in Construction (NRC/IRC). At the NRC, he is researching the wind effects on building envelopes through experiments and computer modeling. He also acts as adjunct professor at the University of Ottawa. He is the vice chairperson for the Roofing Industry Committee on Weather Issues (RICOWI) and a member of ASCE, SPRI, and CIB technical committees. Baskaran has authored and/or co-authored over 125 research articles in the area of wind effects on buildings. "Bas" received his bachelor's degree in engineering from Annamalai University, Madras, India and his master's degree in engineering and Ph.D from Concordia University, Montreal, Canada. Both research topics focused on the wind effects on buildings and earned best disser tation awards from the Canadian Society of Civil engineers.

**Dr. G. Xu**

**Dr. Xu** is a guest worker in NRC/IRC from Soprema Inc., Quebec. He received his B.Sc. in Building Materials Engineering from Chongqing University, Chongqing, China, and his Ph.D in fiber cement hybrid composites from the University of Surrey, Guildford, UK. A professional engineer, Xu's current research interests include the performance and durability of roofing materials and the wind effects on building envelopes.