A Vacuum Powered Soft Textile-Based Clutch Supplementary Information: Withstanding Force

In the array of $(m \times (n+1))$ beads, each bead of a layer coincides with two adjacent beads of the other layer trough the contact points A and B in (Figure S1a,b). Therefore during the interlocking mode under a differential pressure ΔP, the withstanding force of TBC ($F_{engaing}$) is a result of interlocking force generated by all the beads together with friction forces in the two sides of the interlocking zone that are covered by the layers of textile and elastic bands. As following;

$$F_{engaing} = 2 \times m \times n \times F_b + \Delta P \times A_{elastics} \times \mu_{ez} \tag{S1}$$

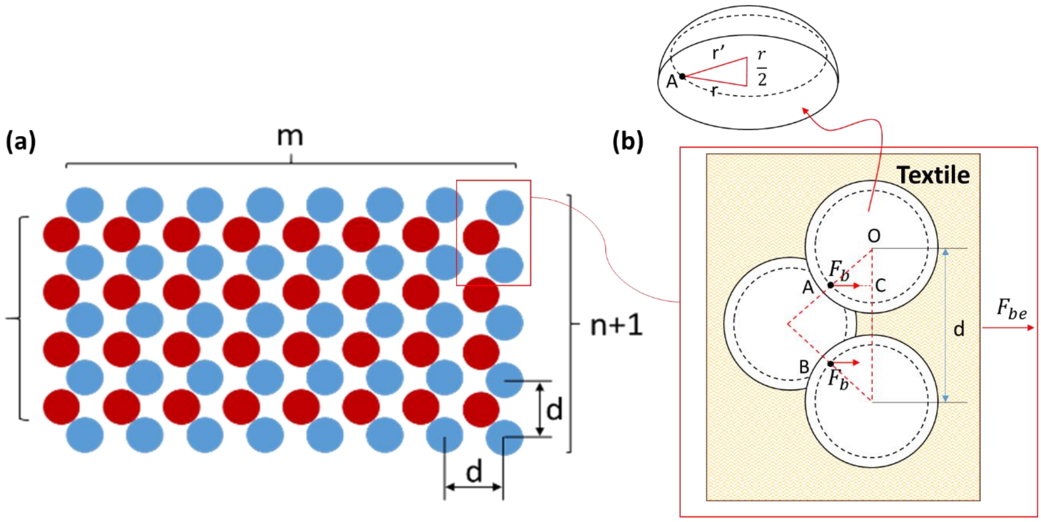

Figure S1. Top view of interlocking beads.

The engaging force of each bead ($F_{be} = 2 \times F_b$) can be calculated based on the vertical force (F_P) caused by the differential pressure (ΔP) and frictional properties of the beads (μ). We can assume a slope (with the angle of α) that passes through the contact points and it is tangent with both beads (Figure S2). The maximum withstanding force generated at each beads happens since the beads do not slide over each other and the contact point on the hypothetical slope (α) does not slide upward, which means;

$$F_{bout} = F_{Pin} + F_f \tag{S2}$$

By substituting $F_{bout} = F_b \cdot cos\alpha$, $F_{Pin} = F_P \cdot sin\alpha$, and $F_f = (F_P \cdot cos\alpha + F_b \cdot sin\alpha) \cdot \mu$, in Equation (S2) we have

$$\begin{gathered}
F_b \cdot cos\alpha \ = F_P \cdot sin\alpha + (F_P \cdot cos\alpha + F_b \cdot sin\alpha)\mu \\
F_b \cdot cos\alpha \ - F_b \cdot sin\alpha \cdot \mu = F_P \cdot sin\alpha + F_P \cdot cos\alpha . \mu \\
F_b \ (cos\alpha \ - \mu \ sin\alpha) = F_P (sin\alpha + \mu cos\alpha) \\
F_b = F_P \left(\frac{sin\alpha + \mu cos\alpha}{cos\alpha \ - \mu \ sin\alpha} \right) = F_P \left(\frac{tan\alpha + \mu}{1 \ - \mu \ tan\alpha} \right)
\end{gathered} \tag{S3}$$

Substituting the Equation (S3) and $F_P = \Delta P \cdot \pi r^2$ (where πr^2 is the area of each bead under the differential pressure ΔP) in Equation (S1) we will have;

$$F_{engaing} = \Delta P \left(A_{elastics} \times \mu_{ez} + 2 \times m \times n \times \pi r^2 \times \frac{tan\alpha + \mu}{1 - \mu \ tan\alpha} \right) \tag{S4}$$

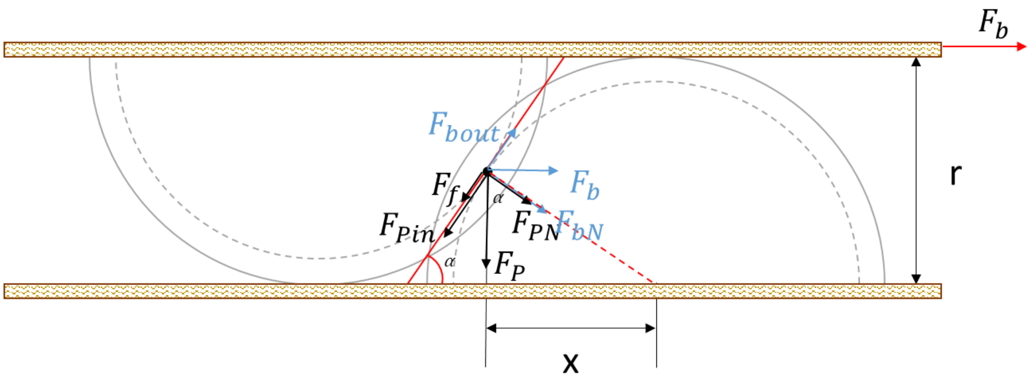

Figure S2. Side view of interlocking beads.

During the interlocking, the minimum distance between belts can decrease down to the beads radius, r, therefore;

$$\tan \alpha = \frac{x}{\frac{r}{2}} = \frac{2x}{r} \tag{S5}$$

The value x can be calculated following Pythagoras theorem for the triangles in Figure S1b. While in the triangle OAC, $AC = x$, $OC = \frac{d}{4}$, we will have:

$$x^2 = r'^2 - (\frac{d}{4})^2 \tag{S6}$$

In Figure S1b, the 3D hemisphere for the depicted triangle we will have:

$$r'^2 = r^2 - (\frac{r}{2})^2 \tag{S7}$$

By substituting the r' value in Equation (S6) we can calculate the value x as follow:

$$x = \frac{\sqrt{12r^2 - d^2}}{4} \tag{S8}$$

In order to guaranty the interlocking between beads the distance between them, d, in the array cannot be greater than value presented in Equation (S7).

$$d < 2\sqrt{3}\, r \tag{S9}$$