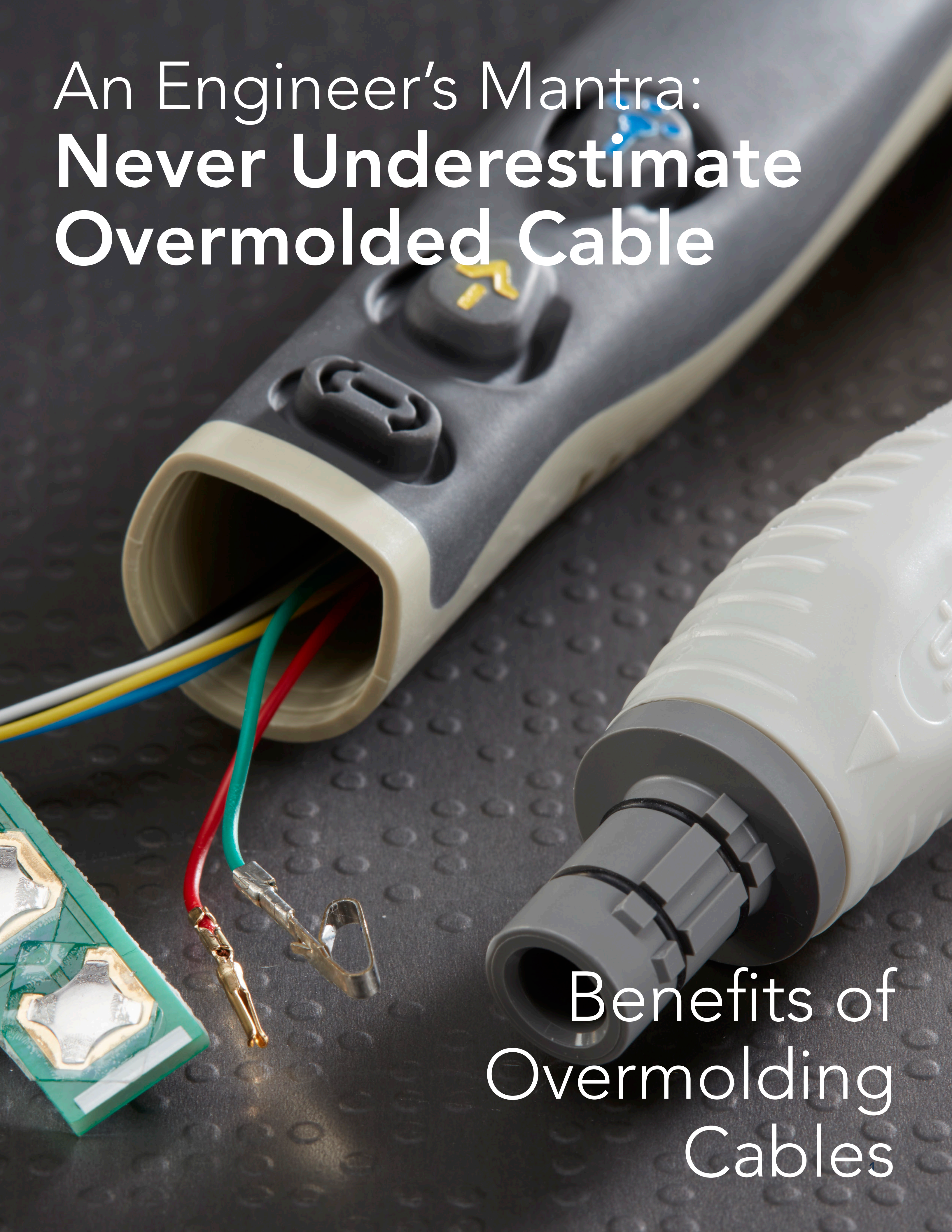
An Engineer’s Mantra: **Never Underestimate Overmolded Cable**



Benefits of Overmolding Cables

Table of Contents

A Summary

The practice of overmolding has proven to be vital to the functionality and appearance of cables. Thanks in part to the development of thermoplastics, overmolded cable assemblies reduce or eliminate many of the risks and disadvantages associated with mechanically assembled cables. The following article outlines the benefits of overmolded cable assemblies and why using over molding shouldn’t be underestimated for use in the most rigorous applications.

Understanding Overmolded Cables

Engineering optimal cables and connectors involves a multitude of decisions to ensure a reliable interconnect solution. One of these decisions that should not be overlooked is overmolding cable assemblies. With the right overmolding technique in place, an overmolded cable can improve performance and reduce total cost.

The majority of over molded cable assemblies are products where the attachment of the electricalconnector to the cable has been placed into a mold and "overmolded" with thermoplastic. This provides a robust and aesthetically attractive product. Figure 1 shows some examples of cable assembly ends with over molded connectors.

Figure 1: Cable assemblies with overmolded connectors.

Overmolding is also used to create breakouts and branches within the length of the cable assembly when required. Comparably, other methods of installing connectors to cables (mechanical assembly) have a few advantages but many disadvantages. To fully understand the benefits of overvmolded cable assemblies, this article reviews the detailed benefits of each style of assembly.

Mechanically Assembled (Non-Over-Molded) Cable Assemblies

Methods other than overmolding involve various mechanical constructions. These cable assemblies may have wires that simply exit the connector with no enclosure and neither a strain relief nor bend relief mechanism. These typically have contacts that are attached to a wire via soldering or crimping, with the contacts subsequently inserted into a housing. Many others have preinstalled contacts with exposed terminals on the back where the wires are attached. These typically rely upon metal or plastic back-shells to enclose the terminations. Examples showing three of these styles are shown in Figure 2.

In connectors such as that shown in figure 2a, the isolation between contacts is created by plastic walls between the contacts. In the case of

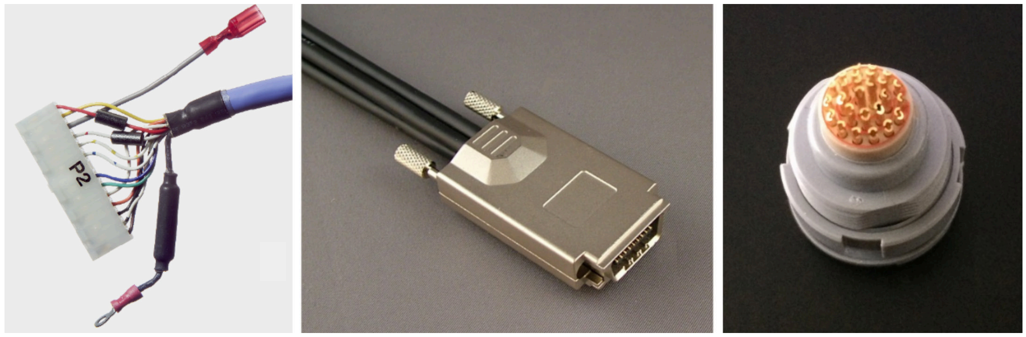


Figure 2: Examples of mechanically assembled connectors.
a) No enclosure
b) metal back shell
c) preinstalled contacts

connectors with pre-loaded pins and exposed contacts on the rear of the connector (Figure 2c), the spacing (air gap) between the contacts determines the isolation factor. This air gap can be inadvertently reduced by excessive or uncontrolled application of solder during termination. Also, flux deposits on the surface of the plastic can harbor conductive particles which further exacerbate potential shorting or dielectric failures.

A method to improve the isolation between contacts that is sometimes employed, is to place a piece of heat shrink tubing over each (or every other) termination. This adds cost from both expensive heat shrink tubing as wells as the associated labor and process variability.

A strain relief is essential to prevent any force applied to the cable from being transmitted to the terminations. Without this, the connection will be susceptible to open circuits and shorts from broken terminations. Strain may involve tying a knot in the cable (if there is adequate space for this) or applying a mechanical anchor clip (such as a hog ring) or mechanical clamp to the cable, just inside the back-shells where the cable exits.

Table 1: Benefits and risks of mechanically assembled connectors

Mechanically Assembled Connectors	
Benefits and Advantages	Risks and Disadvantages
- No over molding equipment or mold tools required	- Shorts due to compromised isolation
- Assembly can be repaired or reworked (only if back shell is not permanently attached)	- Ingress of fluids and corrosive gases resulting in conductor failure
- Space permitting, back-shell can be used to enclose a PCB for incorporating electronics within the connector (Smart Plugs®)	- Potentially inadequate strain relief, bend relief, or both, allowing stress to be applied to the terminations, causing failure of the connection
- Metal back-shells can provide EMC shielding when required	Cost which includes: - Back-shell components - Assembly labor And may also include: - Heat-shrink tubing - Potting - Strain relief - Bend relief
	- Unprofessional aesthetics with the connectors appearing to be “add-ons” as opposed to integrated componenents of the assembly.
	- Removable back-shells allow tampering
	- Standard back-shells complicate customization and custom back-shells involve costly injection mold tooling.

For connectors with back-shells (Figure 2b), the back-shells must be assembled to the connector body. This involves additional labor and potential failure modes. The back-shell systems of many mechanically assembled connectors do not provide a highlevel of environmental protection. Fluid ingress can cause shorts as an immediate failure mode and filed failures from corrosion over time. To overcome this, back-shells are sometimes filled with epoxy potting compounds to encapsulate the connections; a potentially messy process, adding significant cost and labor.

Where the cable exits the back-shell, it can be kinked around the edge of the exit point from the connector body or the hard back-shell by flexing of cable. To overcome this, a sperate bend relief is sometimes applied. These bend reliefs are separate molded elastomer components that are slid onto the cable prior to assembly and then secured to the back-shell by mechanical means such as a flange and groove arrangement or sometimes by gluing.

In summary, mechanically assembled cables have a few benefits in certain circumstances and many disadvantages in most circumstances. Table 1 summarizes the benefits and risks involved with this style of connection.

Overmolded Cable Assemblies

Overmolded cable assemblies reduce or eliminate many of the risks and disadvantages associated with mechanically assembled cables. In most circumstances, over molding employs a two-step process. The two-step process includes the first step of applying an inner mold which is followed by application of the final overmold.

The inner mold is used to encapsulate the terminations and the wires. In most circumstances, omitting the inner mold can allow wires to "float" to the surface during the molding process, resulting in cosmetic defects. The inner mold step precludes this issue because once the inner mold has been accomplished, the wires are securely held. Even if wires have come to the surface of the inner mold, this is not a problem since the wires may no longer move and applying the over mold fully covers the inner mold.

Employing an inner mold also allows the use of multiple materials. This allows use of a less expensive material for the inner mold, followed by a thin and consistent layer of highergrade material for the overmold, to obtain the desired final properties.

Single-step overmolding is sometimes possible with certain geometries. Typically, the distance between the back end of the connector and the end of the cable jacket needs to be very small. The fixturing needs to be able to hold the wires taught so they do not get pushed to the surface of the overmold as easily. The gate (injection point) needs to be located and "aimed" in such a fashion that it minimizes force to the wires and the wall thickness of the overmold needs to be relatively thick to further prevent wires from coming to the surface.

Another single-step over mold process uses a simple, undersized back-shell, with the overmold injected over this simple back-shell. The back-shell can be thin-wall plastic as it requires minimal physical strength since its only role is to keep wires from coming to the surface. Because it gets fully encapsulated, it has no cosmetic requirements, so it can be produced from inexpensive tooling and resins. To capture the benefits of overmolding, the back-shell needs to have holes in it to allow the over mold material to flow into it and thus encapsulate the terminations.

Cost

Overmolded assemblies often have lower material and assembly labor costs by replacing the metal or molded plastic back-shells, strain reliefs and bend reliefs, with less expensive materials and eliminating a great deal of labor. The cost benefits are augmented by the relatively low cost of simple and inexpensive overmold tools, compared to the cost of injection mold tools required for plastic back-shells and bend reliefs.

Isolation

With overmolding, the resin used for the overmold encapsulates the terminations and separates them from each other with materials having superior insulating properties unlike an air gap where ionization can cause arcing (dielectric failure) and tracking (short circuit).

Sealing and Environmental Protection

The same resin that improves isolation can also provide environmental resistance, protecting the terminations from fluids (water-proofing) and other corrosive substances. This eliminates the mechanically assembled connector's need for costly and messy potting process that use expensive materials, require controlled placement and methods to eliminate epoxy propagation during dispensing, and curing times ranging from fractions of an hour to days. Potting also adds process variables that are more difficult to mitigate than with overmolding.

With proper selection of materials, overmolded cable assemblies can be economically produced to withstand repeated exposure to harsh processes such as autoclave, ethylene oxide, vaporized hydrogen peroxide, glutaraldehyde, gamma radiation and other sterilization processes used in the medical device industry. They can also be constructed to withstand continuous exposure to extreme temperatures, other chemicals, submersion and other environmental extremes encountered in other industries and applications.

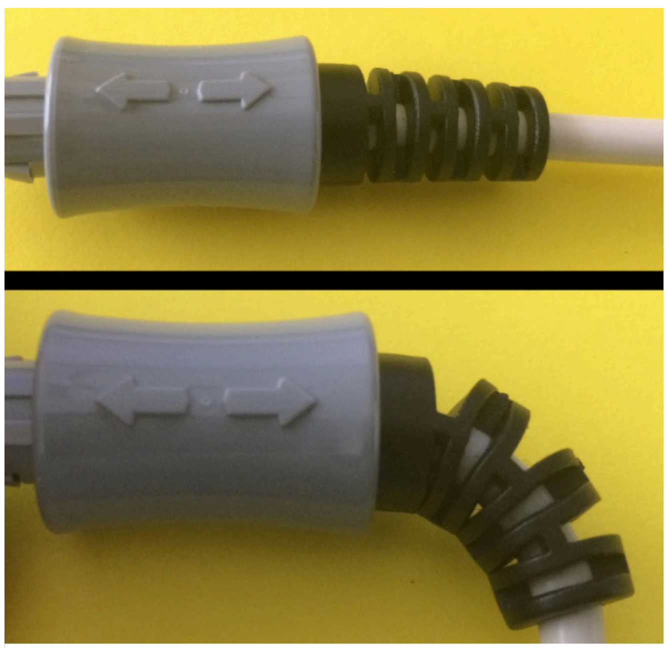
Shock / Vibration Resistance

Since the terminations and individual conductors are encapsulated by the overmold material, motion and resultant fatigue are prevented. When employing soft materials in sufficient thickness, the product is further protected from drop shock by the cushioning effect of the soft overmold material.

Strain Relief

The overmold material encapsulates the terminations and the wires. This provides a first level of strain relief. The overmold can also be formulated to bond with the cable jacket, providing additional strain relief and superior protection of the terminations from mechanical stresses. In cases where exceptional strain relief is required by the application's usage profile, a strain relief clamp (hog ring) can be crimped onto the cable. The overmold material surrounds and securely anchors the clamp into the overmold.

Figure 3: Overmolded bend relief.



Bend relief

Bend relief configurations that are highly effective at limiting the minimum radius of the cable are easy to accomplish. With the overmold bonded to the cable, the bend relief system is very durable. Figure 3 depicts an overmolded bend relief that is bonded to the cable The bonding of the overmolded bend relief to thecable jacket, enhances sealing and strain relief. Limiting the bend radius prevents cable kinking which can result in failure of the jacket and fracturing of conductors.

Appearance and Customziation

Overmolding creates an integrated "made-on-purpose" look. Connectors do not appear as amateurish "add-on" items. Desired size and shape can be produced to accommodate industrial designs complementary to the endproduct, with choice of color and inclusion of logos or other molded-in features.

Soft-Touch

Overmolds can utilize elastomers to create non-slippery, cushioned grips for "soft-touch" feel, enhancing the user's surety and comfort of grip.

Integration of Electronics

It is often desirable to integrate electronics into cable assemblies. This can be done both at the connectors and in breakouts. By applying the appropriate materials, integration of electronics into cable assemblies to create Smart Cables® is accomplished in a very robust and durable manner. The encapsulation of the electronics protects them from mechanical stress and strain and provides superior environmental protection. This is discussed further in a following section focusing on materials.

Breakouts / Branches

Overmolding is not limited to integrating connectors on the ends of a cable. In some applications, cables have breakouts to branch connections to differing locations at one or both ends. Some examples of this are shown in Figure 4. By creating the breakouts with overmolding methods, the same advantages of over molded connectors are realized by the breakouts.

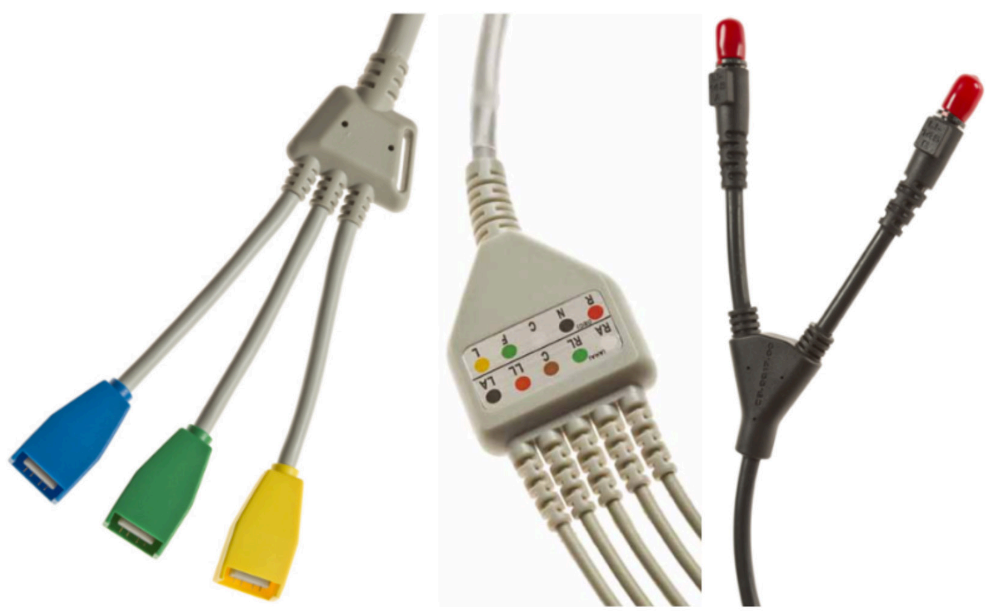


Figure 4: Two overmolded breakouts and an over molded "Y" branch.

Tamper Resistance

Overmolded connections are inherently tamper resistant. It is necessary to destroy the cable assembly to access the terminations.

Tooling

Unlike the injection mold tools required to produce plastic back shells and bend reliefs, overmolds are very simple tools. Typical over molds do not require an ejection system because the cable can be used to lift the over molded section from the tool. Depending on the material, the tooling may not require a cooling system, simplifying it even further.

Not only does this reduce tooling cost (overmold tools can be 1/10th the cost of standard injection mold tools), but the tools can be constructed very quickly. Steel overmold tools can be created in less than two weeks in most cases and when time is of the essence, aluminum tools can be as quick as a few days. Because of this, custom overmolds can offer competitive time-to-market solutions.

Shielding

Mechanically assembled connectors can provide excellent electrical and magnetic shielding with the use of metal back-shells and connector bodies. In cases where overmolded construction is desired, there are metal shelled connectors that are suitable for overmolding. It is also common with plastic bodied connectors, to achieve capable shielding by placing metal shielding "cans" around the back of the connector prior to overmolding. These simple shields are very inexpensive compared to metal bodied connectors and most back-shells.

Materials

Many materials are available for use as over (and inner) molds. Thermoplastics are the most common. Widely used are PVC, TPU, HDPE, LDPE, PP, TPV and TPE. The choice of materials is driven by a number of factors. These include appearance, feel, environmental factors and compatibility with the

Table 2: Common thermoplastics for overmolding.

Commonly Used Thermoplastics for Overmolding

PVC	Polyvinyl Chloride
TPV	Thermoplastic Vulcanizate
ABS	Acrylonitrile Butadiene Styrene
LDPE	Low-Density Polyethylene
HDPE	High-Density Polyethylene
PP	Polypropylene
PA	Polyamide (nylon)
TPY	Thermoplastic Polyurethane

connector and cable jacket materials. For example, with proper processing parameters, a PVC over mold will form a chemical bond to a PVC cable jacket. This provides superior ingress protection, strain relief and bend relief, compared to a material that does not bond to the cable jacket.

TPE and TPV materials are available in many differing chemistries. Selecting the proper resin composition is necessary to achieve a strong chemical bond of the overmold material to the substrates (the connector body, the cable jacket, or both). Major resin suppliers have created a broad offering of TPE and TPV materials, specifically developed to cooperate with common plastics including, ABS, Polyamide (Nylon), PBT and PET (polyesters), PC, PC/ABS alloys and a host of others.

Dependent upon the application, another material property that may need to be considered is regulatory compliance (REACH, RoHS, WEEE, biocompatibility, etc.). When it comes to appearance, materials accept color differently so the ability of a material to achieve a highly specific color (i.e. a customer's "corporate" or trade dress color) may be a consideration. Also to be considered, is the ability to achieve a certain gloss level. TPE and TPV materials tend to have a matte finish while it's very easy to achieve a glossy appearance with TPU. When it comes to feel, materials can range from smooth to porous and from tacky to slippery.

In some cases, it may be desirable to overmold with thermoset materials. A typical example is when over molding a silicone rubber jacketed cable. In this case, using a silicone overmold can create the desired chemical bond. The same holds true for EPDM, Buna N and other thermoset rubber materials.

Low Pressure Molding

An alternate molding process is used when the back of the connector includes electronic components. It is common to include circuitry within the cable assembly for device identification, authentication, use-limiting, anticounterfeiting and a host of other purposes. Components may be directly mounted to connector terminals or are mounted to a small printed circuit board (PCB).

In these cases, Low Pressure Molding (LPM) is used to encapsulate the electronics along with the wire terminations. LPM is done, as the name implies, with very low injection pressure and also at low velocity. This, coupled with use of molding materials with relatively low melt temperatures, allows everything to be encapsulated with no damage to the electronic component assemblies. These materials are often polyamide or urethane based and remain relatively soft, minimizing stresses to solder joints on the PCB both during processing as well as over time and temperature extremes in service.

Anatomy of an Overmolded Connector

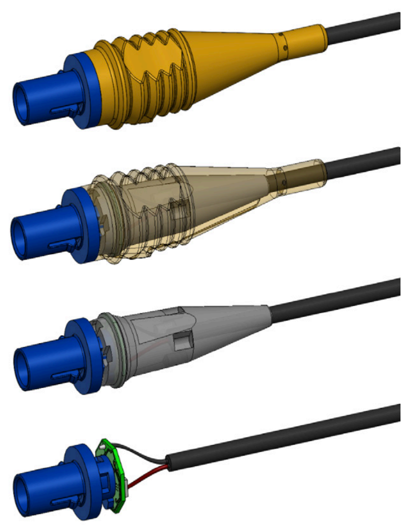


Figure 5: Anatomy of an overmolded connector.

Taking a more detailed look at the construction of an overmolded connector, Figure 5 shows a step-by-step deconstruction of a connector that has been over-molded to a cable with the two-step process. The top image showsthe finished product with a stylized over mold that provides an attractive shape and incudes ribs to provide a nonslip grip of the connector. The overmold material chemically bonds to the cable jacket for sealing and fluid ingress protection.

Shown next is the assembly with the overmold shown transparently to show its relationship to the other components. In this example, the over mold has a long aspect ratio to provide the desired size and shape. Because of this, there are two support pins in the overmold tooling which keep the inner molded assembly centered during injection of the overmold. This results in the finished assembly having two small holes resulting from the support pins. These are the two holes which are visible near the cable exit from the overmold.

The next image shows the assembly with the inner mold applied. The inner mold is designed to occupy as much of the volume as practical with inexpensive material, leaving room for a thin and consistent layer of the final overmold material. The inner mold has features that will mechanically lock the overmold to the inner mold. This allows use of a wide range of material options for the inner mold because it does not need to chemically bond with the overmold.

The final image depicts the wired connector assembly prior to injection of the inner mold. In this example, the connector has a PCB with electronics mounted to the back, to provide Smart Cables® features.

A Side-by-Side Comparison Study

The benefits of overmolded cable assemblies are most effectively demonstrated with a side-by-side comparison of two connectors. In this study, a commonly used, mechanically assembled connector is compared to an overmolded connector. Both are cable-mounted, plug-style connectors. These connectors are equivalent connectors, meaning that they both will mate with the same receptacle; Either one may be substituted for the other in the application. There are, however, few other similarities.

Figure 6 depicts the mechanically assembled connector. From left to right, the components are: connector shell, latch mechanism, pin carrier (with pins installed), collet, collet nut, bend relief and the cable. This connector has six prefabricated injection molded components. The connector shell and latch mechanism are typically provided preassembled. Here they are shown separated for clarity of part count and construction.

Figure 6: Typical mechanically assembled connector.

Figure 7 depicts the connector designed for overmolding. From upper left to upper right, the components are: Connector shell, pin carrier with integral latches (with pins installed) and the cable. This connector has only two prefabricated injection molded components. The lower image of Figure 7 depicts the same connector, terminated and with the inner mold and overmold applied. Sliding the connector shell onto the overmolded sub-assembly would complete the connector assembly. The fully assembled condition of this connector is the center item in Figure 1.

In this case study, a comparison is made between these two connectors and the assembly processes of each. The task is to assemble each connector to the cable with environmentally-sealed terminations.

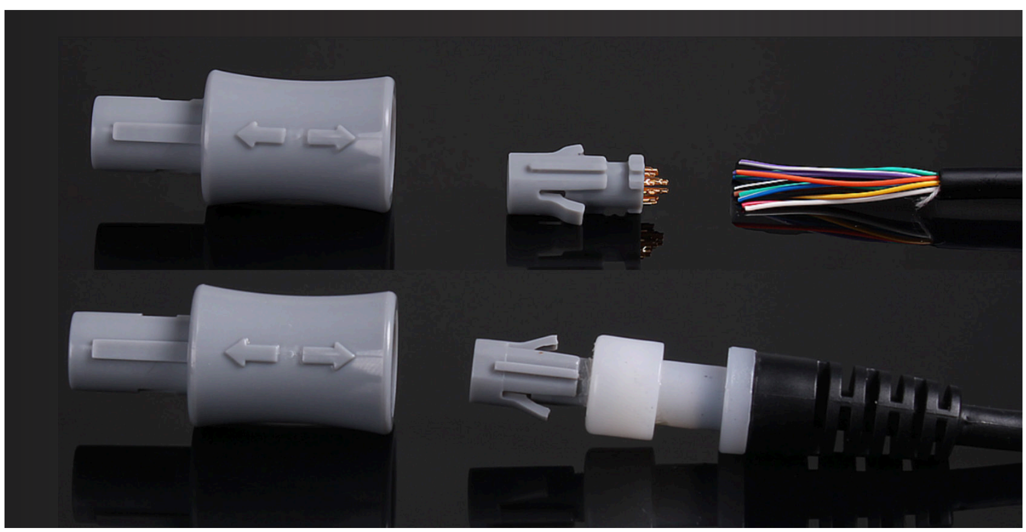


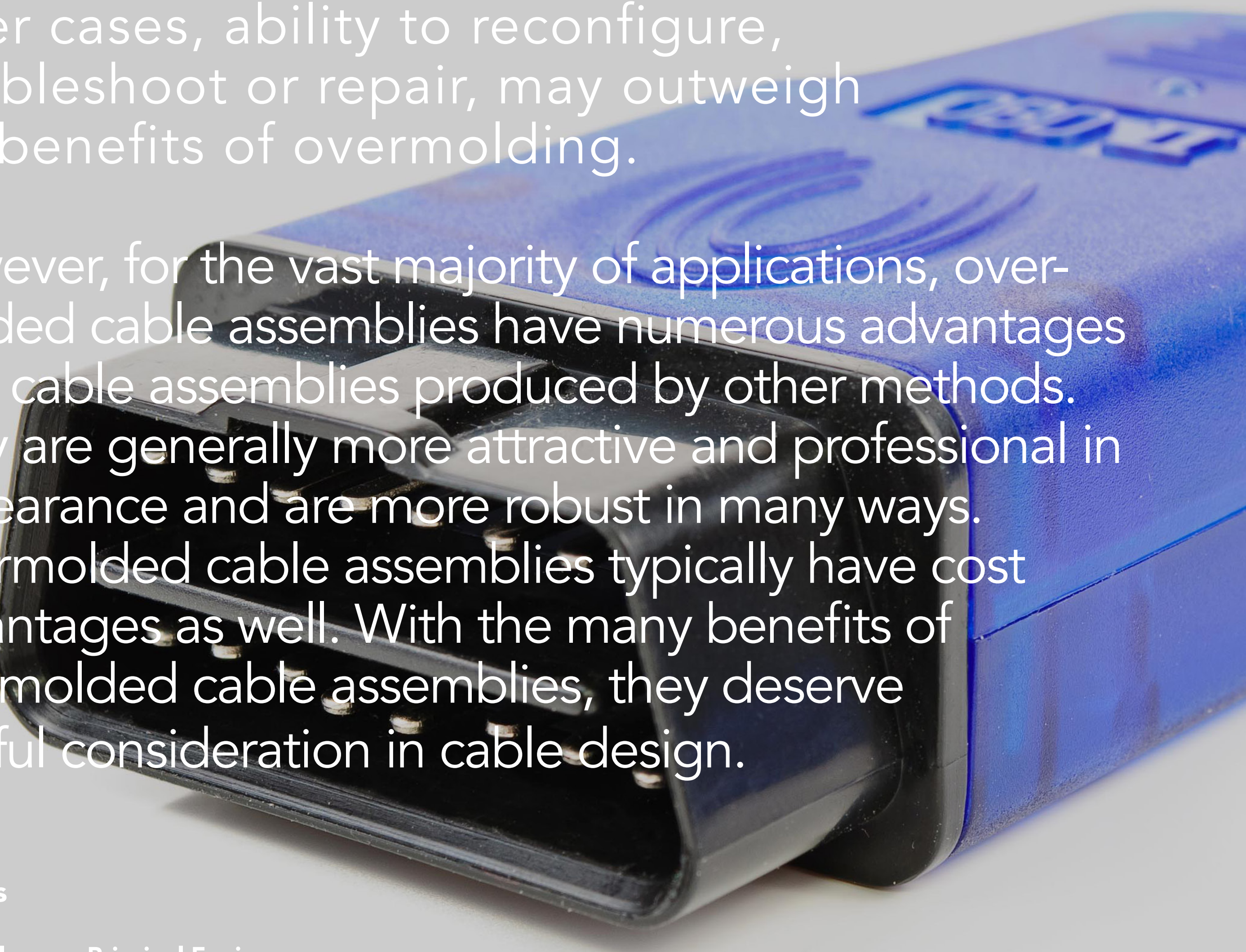
Figure 7: Over-moldable connector shown before termination (top) and then after termination, inner mold and overmold (bottom).

The assembly sequence for these two connectors differs in many ways. Table 3 shows the assembly steps employed for each version and highlights the relative complexity involved in completing the mechanically assembled connector as compared to the simplicity of the overmolded configuration. In both, assume the cable jacket has been cut back (as shown) and the individual wires stripped and tinned for soldering to the connector terminals (stripping not shown).

Table 3: Assembly processes: Overmolded vs mechanical assembly.

Assembly Processes: Overmolded vs. Mechanical		
	Mechanical Assembly	Mechanical Assembly
1	- Solder individual wires to connector terminals.	- Note orientation of bend relief, install over cable and slide up out of the way.
2	- Perform electrical test to verify correct pinout, dielectric withstanding voltage compliance, insulation resistance and connection resistance.	- Note orientation of the collet nut, install over cable and slide up out of the way.
3	- Place terminated connector/cable into molding press and inject inner mold. Inspect for complete fill of the mold.	- Select collet option that is properly sized for the cable diameter being used. Note orientation of collet, install over cable and slide up out of the way.
4	- Place terminated connector/cable into the modling press, inject overmold. Inspect for cosmetic flaws.	- Solder individual wires to connector terminals.
5	- Align key and slide connector shell over the pin carrier, completing the assembly.	- Perform electrical test to verify correct pinout, dielectric withstanding voltage compliance, insulation resistance and connection resistance.
6	- Perform final electrical test to verify correct pinout, dielectric withstanding voltage compliance, insulation resistance and connection resistance.	- Slide collet down the cable, align key with the pin carrier and engage to the pin carrier. Secure collet to the pin carrier using cyanoacrylate adhesive to prevent the collet from becoming misaligned or disengaged from the pin carrier during next step.
7	- Pack for shipment.	- Orient the cable, pin carrier and collet subassembly with the open end of the collet facing up. Mix or otherwise prepare the epoxy potting compound if required. If using a dispensing system, introduce the epoxy potting compound into the dispense receptacle. Exercise care to assure potting does not migrate into an area that will interfere with subsequent assembly steps. Inspect for said condition and clean/rework as required.
8		- Place the sub-assembly from the previous process aside, exercising care to maintain the vertical orientation. Allow epoxy potting compound to cure as specified.
9		- Optionally, repeat electrical testing to verify sub-assembly integrity before additional processing.
10		- Insert the above sub-assembly into the connector shell/ latch assembly, taking care to align the key and fully seat the pin carrier.
11		- Apply thread locker to the collet nut threads.
12		- Slide the collet nut down the cable and thread onto the connector shell/latch. Tighten with a torque wrench to the manufacturer's specified value.
13		- Apply glue to the collet nut for additional security of the bend relief attachment. Slide the bend relief down the cable and engage into the groove on the collet nut.
14		- Peform final electrical test to verify correct pinout, dielectric withstanding voltage compliance, insulation resistance and connection resistance.
15		- Pack for shipment.

Conclusion



There are only a few instances where over-molding may not be the first choice, such as prototyping, laboratory work such as testing interface cables and machinery interfaces and interconnects on the factory floor. In these latter cases, ability to reconfigure, troubleshoot or repair, may outweigh the benefits of overmolding.

However, for the vast majority of applications, over-molded cable assemblies have numerous advantages over cable assemblies produced by other methods. They are generally more attractive and professional in appearance and are more robust in many ways. Overmolded cable assemblies typically have cost advantages as well. With the many benefits of overmolded cable assemblies, they deserve careful consideration in cable design.

Authors

John Holloway - Principal Engineer

John has over 30 years of experience leading teams developing standard and custom interconnect products, primarily for the medical device, military/aerospace and automotive markets. John holds a bachelor's degree in Industrial Technology from Southern Illinois University and an MBA from the University of Rhode Island.