CHEMISTRY THAT MATTERS™

sabic
Specialties

LNP™ KONDUIT™ COMPOUNDS

SABIC'S SPECIALTIES BUSINESS

CONTENT

ABOUT SABIC

SABIC
A GLOBAL LEADER IN CHEMICALS

Ranked among the world's largest petrochemicals manufacturers, SABIC is a public company based in Riyadh, Saudi Arabia. For over 40 years, our ambition to define the future of petrochemicals and thermoplastics has yielded solutions for the challenges of today and helped our customers achieve their ambitions for a better tomorrow.

We believe the answer to some of the world's biggest challenges lies in the natural human instinct to collaborate. We're making sure we understand the megatrends that will impact on our lives in the years to come. We are making a meaningful impact in the world and sustainability is a vital part of our core business strategy.

From enabling energy efficient high-bandwidth datacenters, to making cars and planes more fuel-efficient and helping conserve the world's water supply, we find solutions to the challenges of today to help our customers achieve their ambitions and build a better tomorrow.

LNP™ KONDUIT™ COMPOUNDS

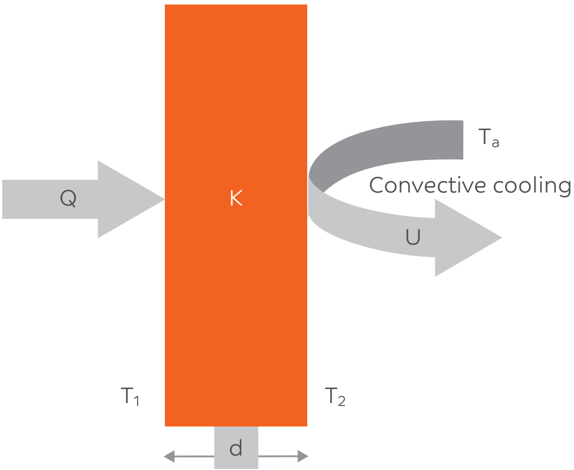
SABIC'S specialties business recognizes the global customer demand for cost effective heat sinks and electronic housings with rising challenges on cost effectiveness, thermal requirements, design freedom, sustainability and material availability (for die-cast parts). Based on these engineering challenges, thermally conductive compounds are already an established alternative in the lighting industry. Additionally, they are becoming an alternative in much more applications – from Automotive to Infrastructure and Industrial applications.

LNP™ KONDUIT™ compounds from SABIC'S specialties business were the first thermally conductive composites commercially available. From 10 to 50 times more thermally conductive than conventional unfilled thermoplastics, KONDUIT compounds can conduct heat away from devices into a heat sink or the surrounding air, designed to extend product life and enhance design freedom.

MECHANISMS IN THERMAL MANAGEMENT

Heat can be dissipated through convection, conduction, and radiation (see righten side). In each application a combination of all three mechanisms play a role.

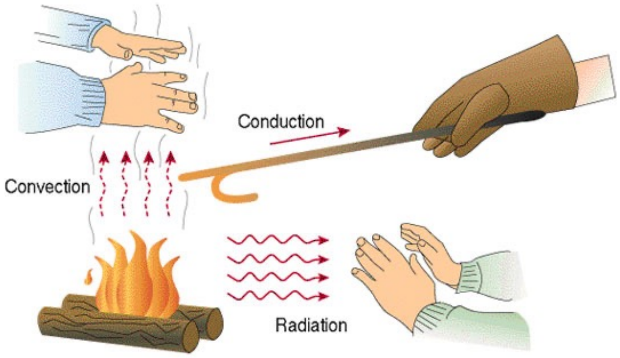
To understand what level of conductivity is required to keep the temperature of an encapsulated power source under control, the following simplified model can be used:



$$\left.\begin{aligned} T_2 - T_a &= Q/(Ah) \\ T_1 - T_2 &= (Qd)/(AK) \end{aligned}\right\} T_1 = Q(dU+K)/(AKU) + T_a$$

Where:

T_2 = the temperature that is generated on the outer wall (°C)
T_1 = the temperature that is generated on the inner wall (°C)
T_a = ambient temperature (°C)
Q = heat transferred in Watt
A = surface area of the flat plate (m^2)
U = heat transfer coefficient (W/m^2K)
K = thermal conductivity (W/mK)
d = thickness plaque (m)



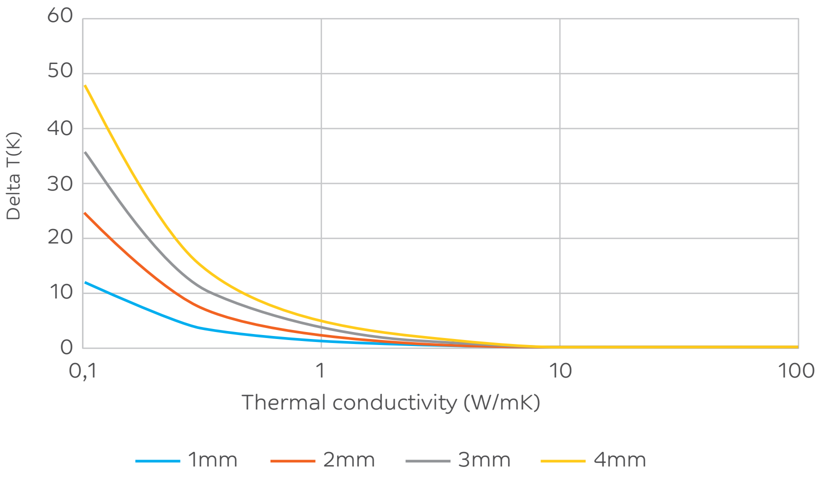
Convection: Mixing of cold and hot air due to pressure difference

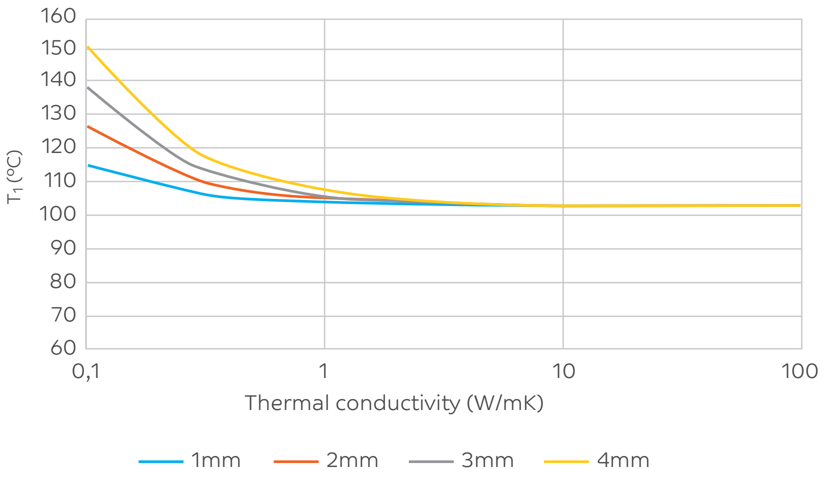
Radiation: Heat transfer via electromagnetic waves → Influenced by amount of surface (design)

Conduction: Transfer of thermal energy due to temperature gradient → Material property!

The heat that is generated by a power source, Q (in Watt), is conducted away through a flat piece with surface A (m^2) and a thickness d (m). When steady state conditions are assumed and radial loss through the edges and heat loss through radiation is neglected the drop in temperature across the wall and the T1 can be calculated. A low T1 corresponds to a good temperature control of the power source. Assuming a surface area of 25 cm^2 (0.0025m^2), a heat transfer of 3 W, free convection (U=15 W/m^2K) and a thickness of 3 mm, the temperature difference across the thickness and the corresponding T1 can be plotted vs. the conductivity of the material at different wall thicknesses.

For low thermal conductivities, the temperature difference or delta T is rather large and here the material conduction is the limiting factor. At higher thermal conductivities, the delta temperature becomes relatively small and here convective heat transfer is the limiting factor and not the material conductivity (see figures on the righten side). This immediately shows that in a convection limited situation, which is often the case, metals (60—200 W/mK) can be replaced by thermally conductive thermoplastics (1-10 W/mK) without significantly increasing part temperature (=T1).

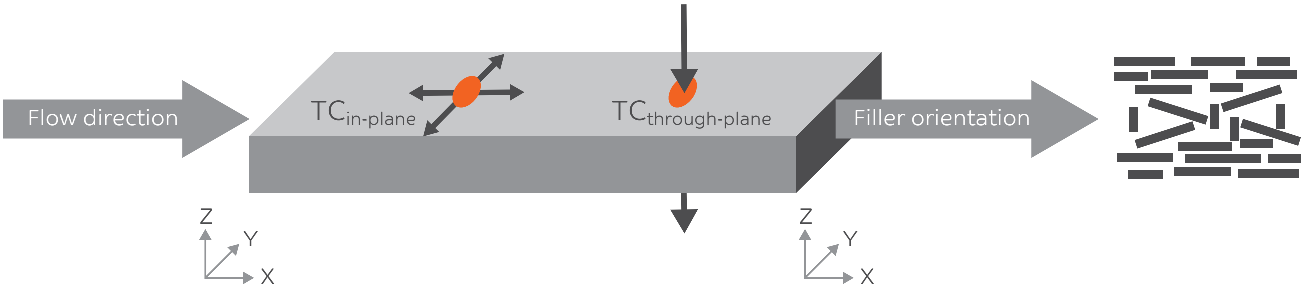




IN CONVECTION LIMITED SITUATIONS, THERMALLY CONDUCTIVE PLASTICS WITH A THERMAL CONDUCTIVITY OF >1W/MK CAN REPLACE METALS WITHOUT INCREASING PART TEMPERATURE.

ANISOTROPIC THERMAL CONDUCTIVITY

Thermally conductive thermoplastics are based on thermally conductive fillers. Often anisotropic fillers, platelets, or fibers are used which tend to orient upon processing leading to anisotropic thermal conductivities in the final molded part.



Isotropic fillers	$TC_x = TC_y = TC_z = TC_{bulk}$
Platelet fillers	$TC_x \sim TC_y \neq TC_z$
Fiber fillers	$TC_x \neq TC_y \neq TC_z$

Modern transient test methods for measuring thermal conductivities (TC) are quick and reliable and capable to distinguish the in-plane and through-plane thermal conductivity. Potentially the thermal conductivity in all 3 directions can be measured but is more labor intensive.

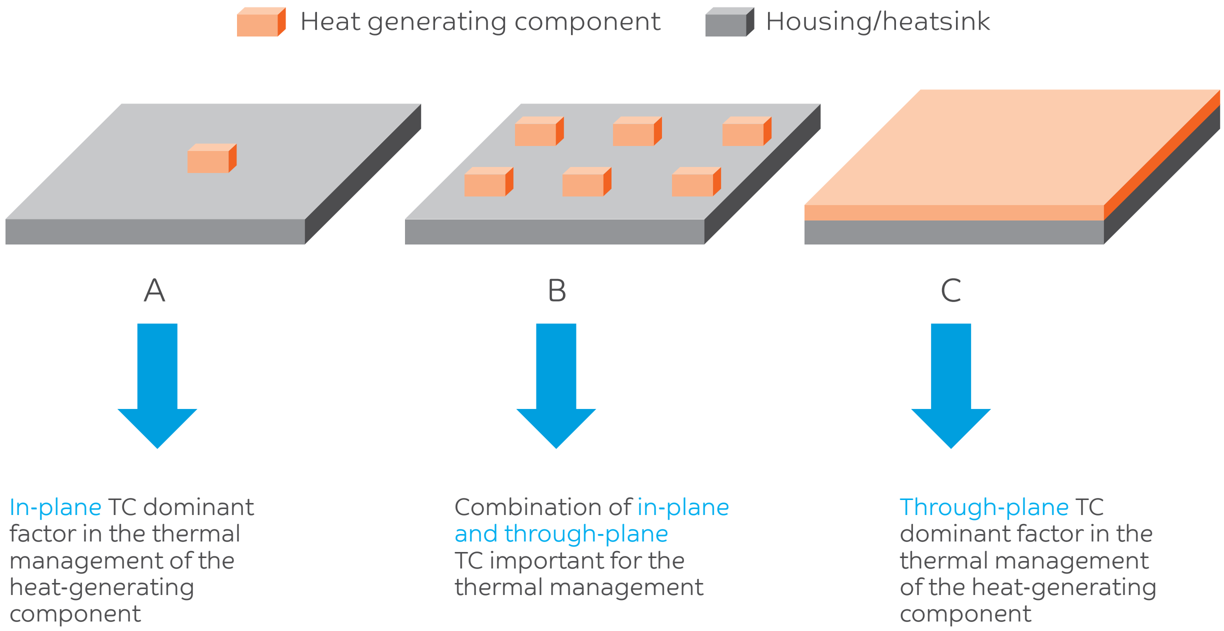
This combined with the fact that platelets fillers are dominant, is the main reason for mentioning only the in-plane and through-plane TC on most datasheets.

This thermally conductive anisotropy has consequences for thermal management and the selection of the right thermally conductive material, as illustrated with the following 3 examples.

In case A there is enough room to spread the heat before conducting it through the material to the ambient. Here a high in-plane thermal TC favors heat transport away from the electronics.

With increasing component density (case B) heat spreading is limited and cooling of the electronics is best served by materials combining both in-plane and through-plane TC, making the bulk thermal conductivity a good choice for a first selection of materials.

In case C the generated heat can only be dissipated through the thickness of the material. In this case the through-plane TC governs the thermal management.



FEATURES AND POTENTIAL BENEFITS

POTENTIAL BENEFITS

- Up to fifty times the thermally conductivity of unfilled thermoplastics, thermosets and epoxies
  - Thermal conductivity up to 13W/mK* for thermally conductive and electrically insulative compounds
  - Thermal conductivity up to 18W/mK* for thermally and electrically conductive compounds
- Processing: injection molding
- UL 1446 (Class H) approved grades available
- Compliance with various ecolabels and other requirements as further described below
- Drops CLTE into the range of most associated metals
- Available in black, grey or bright colors

POTENTIAL BENEFITS VS OTHER POLYMERS

- Reduction in operating temperature / prolonged life of device
- Improved response time for temperature sensing devices
- More power and torque with less current draw and ultimately higher efficiencies
- No complicated 2K or 3K processes

BENEFITS VS DIE-CAST METAL

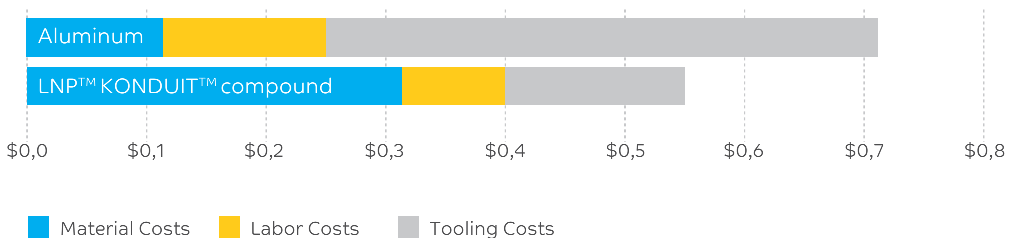
- Benefits through injection molding:
  - Design freedom
  - Part integration, e.g. connectors to electronic housings
  - Component downsizing
- Broader use of assembly technologies possible (e.g. welding)
- Less costs regarding tooling and post-processing
- Lower energy use and lower carbon footprint

CUSTOMER VALUE OF THERMALLY CONDUCTIVE PLASTICS VS DIE-CAST METAL

SYSTEM COST REDUCTION

As a result, from improved productivity through optimized part design, longer lifetime of tooling, lower post-processing (paint elimination) and assembly (welding vs gluing), the use of LNP™ KONDUIT™ compounds generally helps to reduce system costs by 20 to 30%. Injection molding with thermally conductive compounds can be a very good alternative to die-casting metal, especially for parts with less stringent mechanical requirements. The cost reduction is mainly achieved by longer tool lifetime (approx. 10x), optimized designs and resulting lower assembly as well as post-processing (labor costs). Please find an example from a LED lighting application below:

Potential cost savings LNP™ KONDUIT™ compound vs Aluminum (cost per cart)



LEANER, LIGHTER, SAVES MATERIAL

Heat sinks made with LNP KONDUIT compounds with an aluminum insert can be up to 30% lighter than heat sinks made from die-cast aluminum. Pure thermally conductive design, oftentimes optimized for injection molding with part integration, may lead to even higher weight savings.

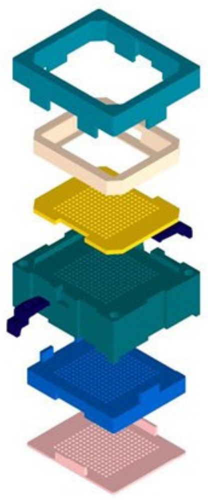
MORE ENVIRONMENTALLY FRIENDLY

Manufacturing and fabricating an LED heat sink with injection-molded LNP KONDUIT compound is less energy intensive than when using die cast aluminum. LED manufacturers can avoid material ,processing costs, associated GHG and energy footprints. Additionally, LNP KONDUIT compounds can comply with the RoHS Directive (2017/2102/EU), the Joint Industry Guide (JIG), the IEC 'halogen-free' standard (IEC 61249-2-21), and ecolabels such as EU Ecolabel, TCO, Blue Angel, and Nordic Swan. Its formulation does not include any of the Substances of Very High Concern as specified under the REACH Regulation (EC 1907/2006).

*LNP™ KONDUIT™ compounds environmental performance is based on SABIC internal analysis following ISO14040 guidelines and principles.

LNPTM KONDUITTM COMPOUND PROPERTIES

The LNPTM KONDUITTM product line from SABIC'S Specialties Businesses comprises of the following bases resins: PA6, PBT (developmental), LCP, PC and PPS. In general, the portfolio can be divided in electrical insulative and electrically conductive materials, with electrically conductive compounds achieving the highest thermal conductivity values and electrically insulative allowing more options for design integration.



THERMALLY CONDUCTIVE KONDUIT COMPOUNDS

		Grade Name	Thermal conductivity, FR rating
Light Color	Electrical Insulative	PX11311U	1.5 / 0.8 W/m·K, UL94-V0 @1.0 mm, WT
		OX11314	1.9 / 0.7 W/m·K, UL94-V0 @ 0.8 mm, WT
		PX13322	3.3 / 1.0 W/m·K UL94-V0 @ 0.8 mm, ALL
		PX11313	1.9 / 0.9 W/m·K, UL94-V0 @ 0.8 mm, WT
		8TF36E	4.5 / 1.0 W/m·K (ASTM E1461-07)
Light & Gray Color	Electrical Insulative	DTK22	2.0 / 0.6 W/m·K, UL94-HB @ 0.8 mm, ALL
Dark Color	Electrical Insulative	PX13012	5.5 / 1.2 W/m·K, UL94-V0 @ 0.8 mm, BK
		OX11315	13 / 0.8 W/m·K, UL94-V0 @ 1.0 mm, NC
		8TF29E	9.0 / 2.0 W/m·K (ASTM E1461-07)
	Electrical Conductive	OX10324	18 / 1.3 W/m·K UL94-V0 @ 1.2 mm, NC
		PX10323	18 / 1.5 W/m·K UL94-HB @ 0.75 mm, NC

Thermal conductivity, in-plane / through-plane*

PX: PA6 based, OX: PPS based, DTK: PC based, 8TF: LCP based, PBT based grades in development
* Thermal conductivity measured with Hot disk TPS2500; In-plane with a 3mm plate (60 by 60mm, film-gated).
Non-brominated, non chlorinated flame-retardant system

LNP™ KONDUIT™ COMPOUND POTENTIAL APPLICATIONS

INFRASTRUCTURE LIGHTING

Heat sinks, integral to the efficacy and longevity of an LED, constitute a significant portion of LED cost. LNP™ KONDUIT™ compounds are a cost-effective, resource efficient heat sink solution that can contribute to the scaling of LEDs.

Potential solution:
PX10323, OX10324

AUTOMOTIVE LIGHTING

Heat sinks, integral to the efficacy and longevity of an LED, constitute a significant portion of LED cost. LNP KONDUIT compounds are a cost-effective, resource efficient heat sink solution that can contribute to the scaling of LEDs.

Potential solution:
PX10323, OX10324

SEMICONDUCTORS

Heat sinks, integral to the efficacy and longevity of an LED, constitute a significant portion of LED cost. LNP KONDUIT compounds are a cost-effective, resource efficient heat sink solution that can contribute to the scaling of LEDs.

Potential solution:
PX10323, OX10324

ELECTRONIC HOUSINGS

Heat sinks, integral to the efficacy and longevity of an LED, constitute a significant portion of LED cost. LNP KONDUIT compounds are a cost-effective, resource efficient heat sink solution that can contribute to the scaling of LEDs.

Potential solution:
PX10323, OX10324

COIL WOUND SYSTEMS

Heat sinks, integral to the efficacy and longevity of an LED, constitute a significant portion of LED cost. LNP KONDUIT compounds are a cost-effective, resource efficient heat sink solution that can contribute to the scaling of LEDs.

Potential solution:
PX10323, OX10324

CONNECTORS

Heat sinks, integral to the efficacy and longevity of an LED, constitute a significant portion of LED cost. LNP KONDUIT compounds are a cost-effective, resource efficient heat sink solution that can contribute to the scaling of LEDs.

Potential solution:
PX10323, OX10324

Automotive front light

Solenoid pneumatic valve

SABIC CAPABILITIES FOR DESIGN SUPPORT

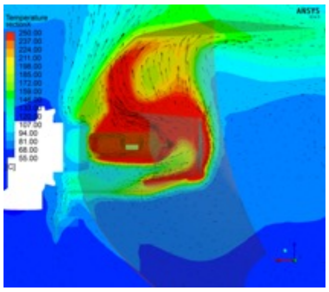
Traditionally, aluminum is the preferred material for heatsink in LED luminaires. As the major mode for heat transfer to the atmosphere is natural convection, the overall convective heat transfer is limited, and the high thermal conductivity of metals cannot be effectively utilized. Through proper design, the performance of aluminum heatsinks can be matched by thermally conductive polymeric heatsinks. By leveraging the use of Computational Fluid Dynamics (CFD) software the effect of design iterations on the overall thermal management can be predicted and the timelines for development can be significantly reduced. This approach was used in a demonstrator project and the finalized design was then prototyped and the actual performance of the assembled LED luminaire prototype matched the simulation predictions.

SABIC'S SPECIALTIES CAPABILITIES TO SUPPORT THERMAL SIMULATION

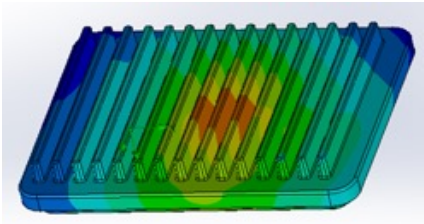
SABIC'S Specialties Application Development Center in Bangalore has a broad experience in simulation with commonly used thermal and CFD analysis tools like Ansys FLUENT, Mentor Graphics FloEFD, CFD 3D, AcuSolve, Polyflow and Comsol.

Our simulation team is used to support customers in different types of simulation:

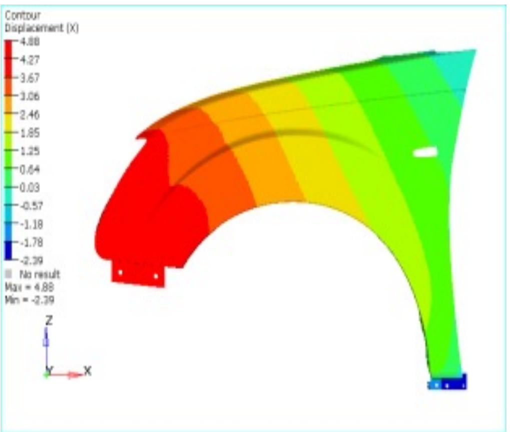
- Simulation of conduction, convection & radiation heat transfer modes
- Simulating natural/forced convection fluid flow
- Multi-phase flow simulations
- Coupled thermo-mechanical simulations



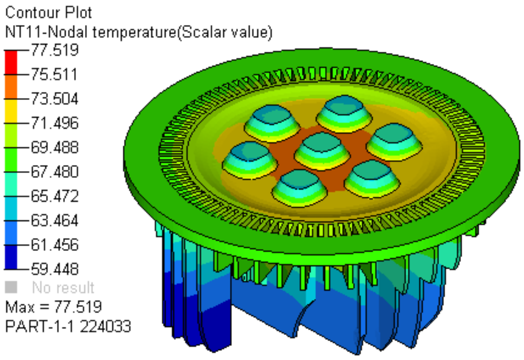
Heat Transfer



Heat Sink



Thermo-Mechanical



LED Thermal

CASE STUDY: INFRASTRUCTURE LIGHTING

CUSTOMER CHALLENGES

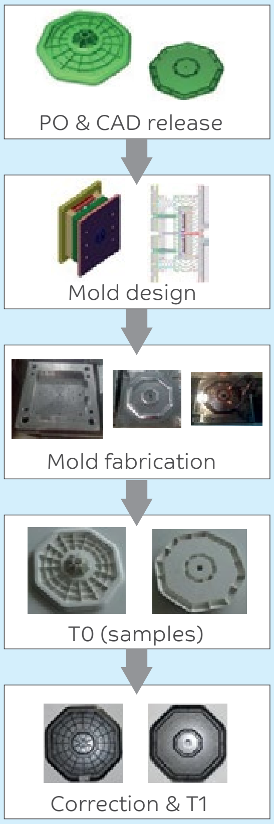
- Customer looked for weight and cost out solutions vs die-cast aluminum streetlight heat sinks
- Mass production of streetlights

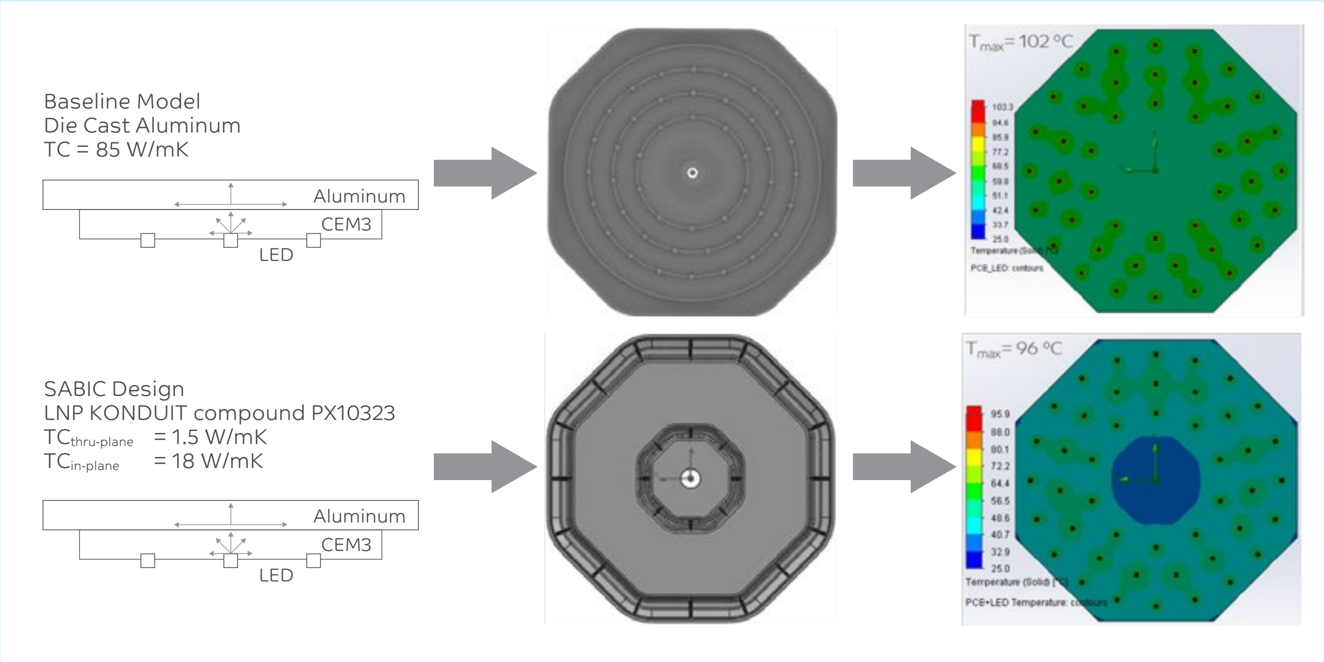
SABIC SUPPORT

- Moldability study and mold design support
  - Understanding of material requirements, including mechanical, impact and thermal requirements
  - Design of heat sinks to have a similar performance to incumbent die-cast Aluminum solution
  - Moldflow study
  - Support mold design, including tool construction as well as runner and ejector systems
- Thermal studies using FloEFD (see below)
- Prototyping at SABIC Bangalore

OUTCOME

Feasibility of using thermally conductive plastics to streetlight heatsinks – study applied to several customers.





LIFE CYCLE ASSESSMENT – LNPTM KONDUITTM COMPOUNDS VS DIE-CAST

The following case study on LCA benefits is done on a LED heat-sinks for lighting applications made of a typical LNPTM KONDUITTM compounds and die-cast aluminum part . Potential design optimization for plastics was not considered.

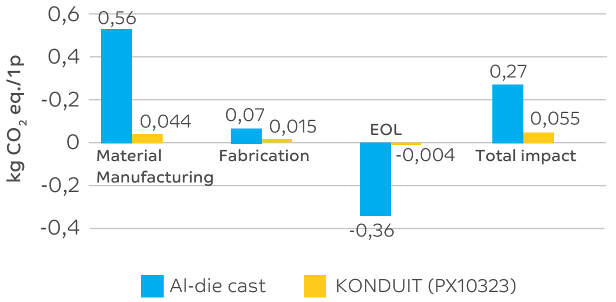
CRADLE TO CRADLE LCA DATA[1]

ENVIRONMENTAL PERFORMANCE[1,2]	LNP KONDUIT PX10323 VS. ALUMINUM DIE CAST[3]
Green House Gas (GHG) emission reduction/LED heat sink	82%
Commulative Energy Demand (CED)/ LED heat sink	80%

GREEN HOUSE GAS EMISSION

LNPTM KONDUITTM compounds have significantly lower GHG emissions compared to aluminum die cast over the full product life.
During its sourcing, manufacturing, fabrication and end of life, an aluminum die cast LED heat sink has 82% higher Green House Gas (GHG) emission impact compared to LNP KONDUIT heat sink.

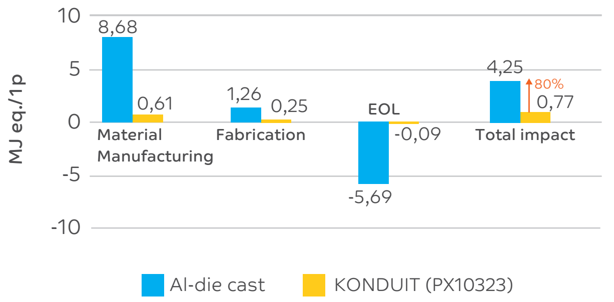
C-to-C GHG Emission of LED Heat Sink (Aluminium vs. Non-Hybrid Konduit)



ENERGY EFFICIENCY

In terms of energy demand, a typical aluminum die cast LED heat sink has a 80% higher commulative energy demand (CED) compared to an LNP KONDUIT heat sink. This includes the sourcing, manufacturing, fabrication and end-of-life of the LED heat sink in both cases.

C-to-C Commulative Energy Demand of LED Heat Sink (Aluminium vs. Non-Hybrid Konduit)



CLEANER CHEMISTRY[4]

LNP KONDUIT compounds may be used to comply with the RoHS (Restriction of Hazardous Substances; EU Directive 2002/95/EC), do not contain REACH Substances of Very High Concern above 0.1% by weight (SVHC; as defined by EU Regulation EC 1907/2006 and updated 18 Jun 2012), and meet the certification requirements for the Global Automotive Declarable Substances List (GADSL) and the Joint Industry Guide (JIG), as verified in January 2013.

VERIFIED ENVIRONMENTAL PERFORMANCE

SABIC'S SPECIALTIES BUSINESS partners with GreenOrder, a leading sustainability consulting firm, to provide third-party technical analysis and verification of Sustainability Solutions benefit claims.

GreenOrder | Verified environmental performance

REFERENCES

[1] Scope of this LCA study includes raw material extraction, manufacturing, fabrication, use, and end of life stages of product life cycle. The LCA study is performed based on ISO14040/44 framework. The functional unit used in this study is 1 piece of LED heat sink made with LNP KONDUIT compounds AND Die cast Aluminum.

[2] Based on Ecoinvent database.

[3] Specifications of one piece (1p) LED heat sink made with Aluminum die cast: Weight = 16 g,
Specifications of one piece (1p) LED heat sink made with Konduit PX10323: Weight = 9,72g

[4] The Restriction of Hazardous Substances Directive (RoHS) and the EU REACH regulation EC 1907/2006 are internationally recognized environmental directives and regulations for hazardous materials. The American Chemistry Council Global Automotive Declarable Substances List and the Consumer Electronics Association Joint Industry Guide each provide a list of substances and materials requiring declaration according to law or regulation.

DESIGN WITH LNP™ KONDUIT™ COMPOUNDS

PART DESIGN
Performance of parts made from LNP™ KONDUIT™ compounds depends on the compound properties, part design, and the molding process. Good part design is critical for meeting application structural requirements and molding productivity. Assembly requirements should also be considered during the design stage.

PART DESIGN PROCESS
The design process can be simplified by following a three-stage approach where material, design and fabrication decisions are made in parallel. SABIC's Specialties engineers should be consulted during the early stages of the design process. Additional information on each of the steps can be found in the LNP Specialty Compound Design Guide. The following guidelines are reminders of good design practice aimed at producing quality injection molded parts.

PRELIMINARY STAGE
- Define requirements
- Establish conceptual geometry
- Select materials
- Select fabrication method
- Perform feasibility analysis
- Decision to move forward

ENGINEERING STAGE
- Complete detailed part design
- Fabrication decisions
- Material decisions
- Prototype testing
- Evaluation and redesign

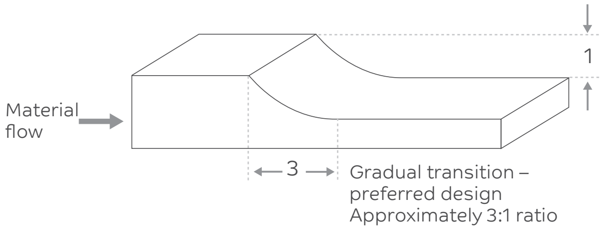
MANUFACTURING STAGE
- Design, build and evaluate a tool
- Cavity filling analysis
- Manufacturing equipment selection
- Part testing
- Customer evaluation

PART DESIGN PROCESS
Part geometry is critical to achieving a well-molded part. Considerations include:

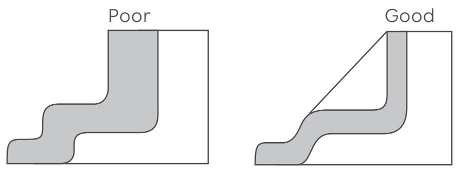
WALL THICKNESS
Uniform wall thickness throughout the part and attention to nominal thickness is important. (See guidelines below)

Uniformity
- Residual stresses (warpage, sinking, chemical resistance)
- Mechanical properties (strength, impact resistance)

Nominal thickness
- Agency approvals (flammability)
- Processibility (flow, length, cycle time)
- Maximum thickness based on polymer system



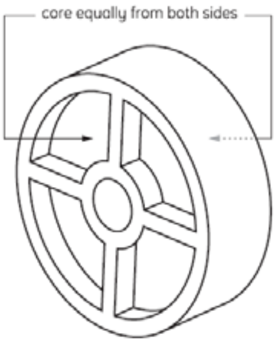
Wall transition design



Variable wall section diagram

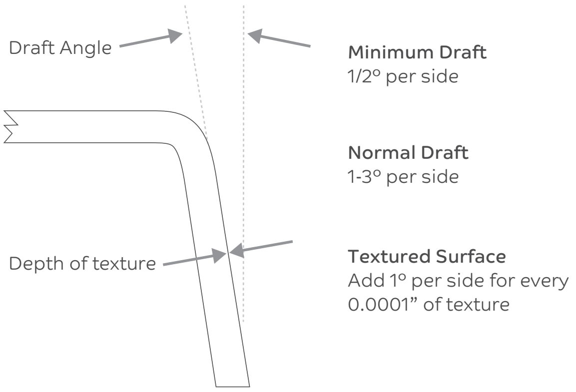
DESIGN WITH LNP™ KONDUIT™ COMPOUNDS

CORING
Core thick areas of the part to maintain uniform wall sections and even cooling.

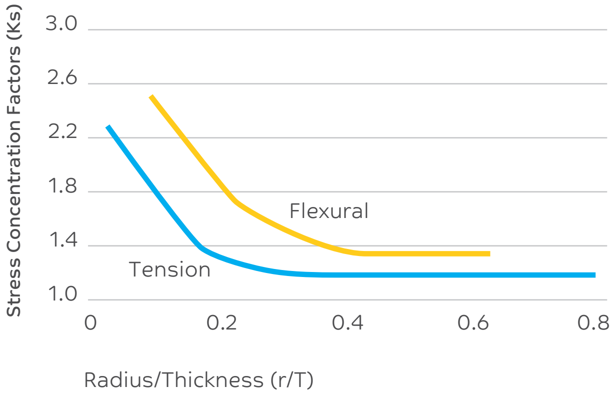


Goal: Uniform wall with even pressure distribution and even cooling

DRAFT ANGLE
All part walls should have 2°–3° draft per side whenever possible, with a minimum of 1° draft since reinforced compounds shrink less than neat resins. Unfilled compounds should maintain 1/2° draft per side minimum. Textured surfaces require an additional 1° draft per side for every 0.001” depth of texture.



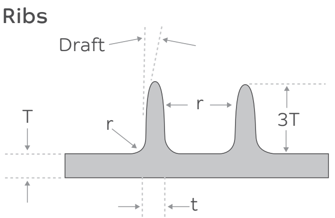
RADII
Sharp corners cause stress concentrations and should be avoided. See guidelines below for proper corner radii.

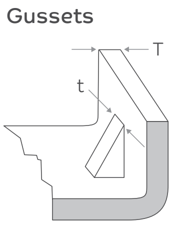


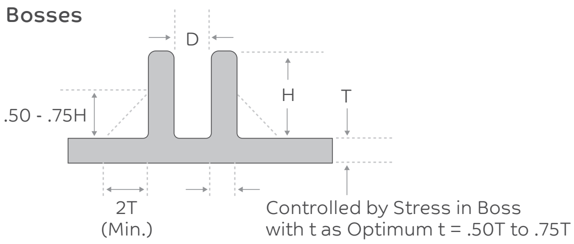
General Rules
r_{in} = .25T (Min.)
r_{in} = .50T (Better)
r_{in} = .75T (Best)

Trade-off is thick sections
$r_{out} = r_{in} + T$

RIBS/BOSSES/GUSSETS
Ejection problems or thick sections (sink marks) may result from improperly designed ribs, bosses, or gussets. Long core pins may overheat or deflect if not designed properly. Unsupported pins should have an L/D of < 5/1. Copper alloys may be used to provide better cooling of long core pins.







SHRINKAGE AND TOLERANCES

Typical shrinkage of glass-fiber-reinforced compounds will be one-third to one-half that of non-reinforced resin. We recommend starting with a prototype tool to determine exact shrinkage, particularly on parts with complex shapes or drastic variations in wall thickness. Parts molded from compounds which exhibit anisotropic shrinkage characteristics (reinforced, crystalline resins) should also be prototyped initially or molded on a "surrogate" tool in order to predict critical shrinkage results. In general, reinforced compounds can be molded to tighter tolerances than unfilled materials. Holding tight tolerances can significantly increase the cost of a molded part since designing for close tolerances may add steps to the manufacturing process or require higher tooling costs compared to coarse tolerances.

WELD-LINES

Proper tool design (gate location, etc.) can help minimize the formation of weld-lines. If they cannot be avoided, they should be located in the area of the part where minimal applied stress is expected.

Our experience with LNP compounds and weld-lines has shown that:

- Weld-line tensile strength of filled or reinforced resins depends partly on the inherent weld-line integrity of the base resin.
- Fibrous reinforcement, which orients parallel to the weld-line, can cause dramatic loss of strength in the weld-line area. The amount of decrease is directly related to the volume of reinforcement.
- Particulate fillers do not affect weld-line strength to such a degree.
- Part thickness has little or no effect on weld-line tensile strength, although thicker walls usually reduce stress.
- Molding variables – other than hold time — do not significantly affect weld-line strength.
- Optimized venting should be provided at the weld-line to maximize weld-line strength.
- Overflow tabs do not improve weld-line strength enough to justify the corresponding increase in cost.

PROCESSING

DRYING

Most resins require thorough drying prior to injection molding to assure maximum properties in the molded part. The drying requirements followed for the base resins are generally the same for the compounds produced from them. Drying is recommended for the compounds made from these resins since the pellets may retain surface moisture. The drying parameters listed below are applicable to all LNP compounds.

The drying temperature can vary and are listed in the specific LNP™ KONDUIT™ product datasheets with a view listed in the below table.

Minimum drying time 3–4 hours with a -31°F (-35°C) or less dewpoint.

A machine-mounted, dehumidifying hopper dryer equipped with a closed-loop circulating air system is preferred. When bulk drying, ensure resin remains dry via positive flow of dry air through the conveying system.

The hopper dryer should be equipped with a diffuser cone to ensure proper distribution of air flow and allow "plug flow" of material through the hopper.

Batch drying can be accomplished with air circulating, desiccant tray dryers with trays filled to a depth of no more than 1" (25mm). Material dried in this manner should be placed in a sealed hopper and residence time kept to a minimum.

KONDUIT	Dry temperature (°C)	Dry time(hrs)
OX10324	120 – 150	4
PX10323	80 – 90	3 – 4
PX11311U	80	4

MACHINE PREPARATION

Prior to introducing LNP compounds, the molding machine barrel should be thoroughly cleaned either by purging or mechanically cleaning the cylinder with brass wool. If the screw is removed, clean it also and check carefully for nicks, cracks, or excessive wear. The check ring should also be inspected for any abnormalities. To check for cleanliness without removing the screw, purge with an unfilled, amorphous resin such as polystyrene or polycarbonate and look for foreign particles or discoloration in the air shot. Any evidence of contamination in the first several molded parts may suggest that the cleaning procedure should be repeated.

MELT TEMPERATURE

The exact molding conditions depend on machine configuration, tool and part design. However, the temperature should fall within the following range which is mentioned in the specific product datasheet. It is important not to create long residence times which can result in material degradation. The ideal maximum residence time is between 6 and 12 minutes, depending on the selected melt temperature.

KONDUIT	Melt temperature (°C)
OX10324	320 - 350
PX10323	270 - 300
PX11311U	270 - 295

INJECTION PRESSURE AND SPEED

Injection pressure will vary with part size and configuration. In general, the injection fill rate should be as rapid as possible, especially for thin-walled parts. Thick-walled parts should be filled using moderately slow injection rates. Be aware that with high pressures and fast injection fiber breakage might happen and settings should be optimized.

Regular injection pressure of 10 –15,000 psi (70–105 MPa) and injection speed of 3-7 in/sec (25-175 mm/sec) are normally adequate for LNP KONDUIT compounds, depending on the tool design.

CUSHION

A minimal amount of cushion should be provided. Normally a range of 3 - 6 mm cushion will allow for adequate compensation of shot-to-shot variation. A minimal amount of cushion will also provide better pressure transfer on the melt.

BACK PRESSURE

Highly filled LNP KONDUIT compounds are less compressible relative to unfilled engineered thermoplastics. This allows for low back pressures. Generally, the back pressure should be kept as low as possible. In order to minimize fiber breakage a maximum back pressure of 4 – 6 bar is recommended.

SCREW SPEED

A screw speed between 0.15 – 0.25 mtr/sec is sufficient for most LNP KONDUIT compounds. High screw speeds can result in over heating of the melt and increased residence time in the molding machine.

NOZZLE TEMPERATURE

Full-length nozzle heater bands should be controlled separately from the front barrel zone. Closed-loop, thermocouple-controlled heating elements will help achieve a uniform melt temperature. The nozzle temperature setting should approximate the desired melt temperature.

MOLD TEMPERATURE

LNP KONDUIT compounds should always be molded in temperature-controlled molds.

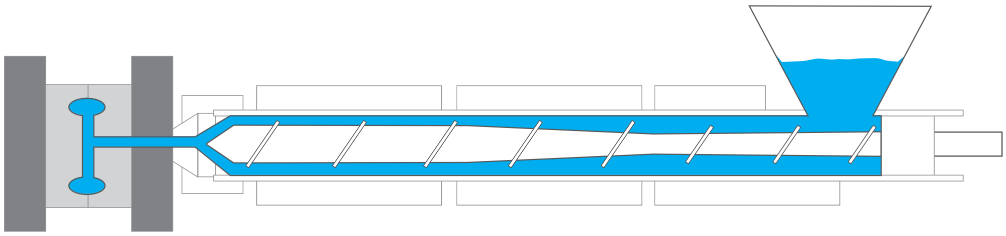
Individual and accurate control of each mold half in the ranges shown on the process chart assures the best results

Large cores or small diameter core pins may require lower temperatures or special cooling control to aid part ejection. High mold temperatures are required for thermally conductive resins compared to conventional engineered resins. The mold temperature should be set to a temperature range, that allows the resin to solidify and reach the mechanical integrity for ejection of the part from the mold.

KONDUIT	Mold temperature (°C)
OX10324	110 - 150
PX10323	80 - 100
PX11311U	85 - 100

CYCLE TIME

Cooling time is the major portion of the total molding cycle. The cooling requirements are dependent on the part thickness and the level of filler in the resin. Fiber reinforced LNP KONDUIT compounds will cool faster than unfilled resins due to the higher thermal diffusivity of these materials.



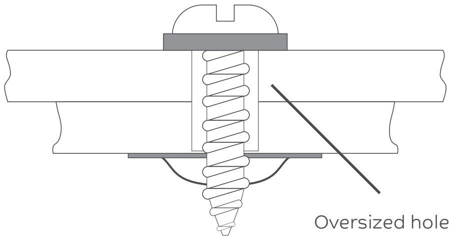
SECONDARY OPERATIONS

Although most parts made from LNP™ KONDUIT™ compounds are molded as finished components, the design and ultimate use of certain parts may require machining, assembly or finishing operations. LNP KONDUIT compounds makes a wide variety of secondary operations available to the design engineer. General recommendations for these operations are as follows:

WELDING

Welding is a commonly used permanent assembly technique for engineering thermoplastics. LNP™ KONDUIT™ parts can be welded using different processes. Selecting the right process depends on the size, shape and function of the part:

- Laser Welding is based on the characteristics of plastics on laser-transmission, -reflection and -absorption at certain wavelength. Depending on the characteristics of the LNP KONDUIT compound a decent joint strength can be reached
- Ultrasonic Welding is commonly used. Welding amplitudes with 20 kHz ultrasonic processes should be in the range of 80 – 120μm
- Hot Plate Welding allows excellent weld strengths to be achieved at temperatures of 270°C - 350°C/518°F - 662°F depending on type of KONDUIT compound
- Friction Welding can be applied, using either the vibration, orbital or rotation method



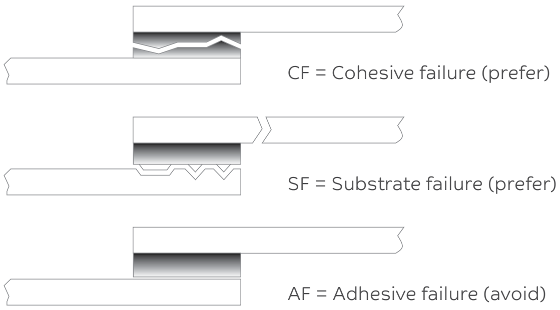
MECHANICAL ASSEMBLY

Mechanical assembly techniques are widely usedwith LNP KONDUIT parts. To achieve optimum results, mechanical fasteners should be kept free from oil and grease. Depending on the type of fastener, a permanent stress or deformation is applied locally. Clamp forces should be controlled or distributed over a large surface area. This is in order to decrease local stresses in the part after assembly and to minimize the risk of loosening the fasteners through creep and relaxation. Notches in the design as well as notches resulting from mechanical fasteners should also be avoided. Recommended assembly techniques:

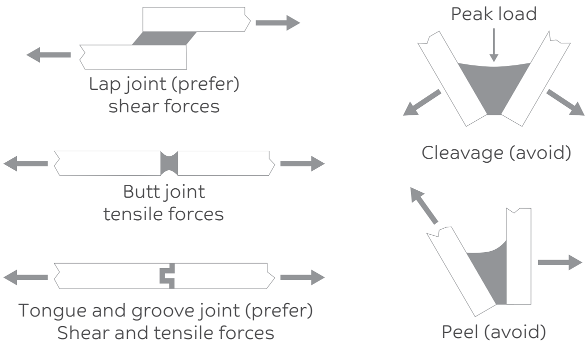
- A wide range of EJOT PT screws are recommended to use for the PX10323, PX1131U and OX10324. With a broad range of tightening torque, depending on the size and depth of the screw.
- Inserts which leave low residual stresses can be used. Installation by heat or ultrasound are the preferred techniques. Press and expansion inserts produce high hoop stresses in bosses and should therefore be used with caution
  - Snap fit assembly
  - Rivets
  - Staking

SECONDARY OPERATIONS – ADHESIVE BONDING

Adhesive bonding is a convenient method of assembling a plastic part to either a similar or dissimilar (including non-plastic) material. Adhesives distribute stresses over the entire bond area and can provide a hermetic seal if needed. Flexible adhesives allow some movement between mating parts, and thus can compensate for differences between the materials, such as coefficient of thermal expansion. Adhesives are relatively inexpensive and often require little or no special equipment for application.



Joint design is critical to the optimum performance of a bond. Joint orientation will define the type of loading applied to the bond - shear, peel, tensile, etc.



LNP™ KONDUIT™ parts can be bonded to other plastics, glass, aluminum, brass, steel, wood and other materials. A wide variety of adhesives can be used, sometimes with the addition of a surface treatment In general, LNP KONDUIT parts can be easily bonded acrylic, urethane, MMA, silicone and Epoxy type of adhesives.

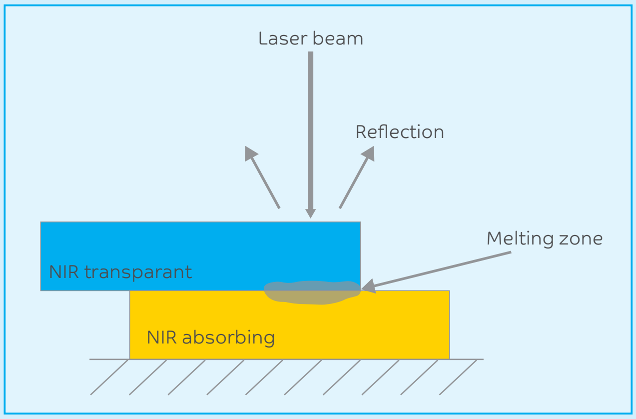
Type	Company	Brand	LNP KONDUIT OX10324	LNP KONDUIT PX11311U	LNP KONDUIT PX10323
Acrylic	3M	DP8005	Good	Good	Good
	3M	DP8010	Poor	Medium	Poor
	3M	DP8610	Poor	Poor	Poor
	3M	DP8910	Poor	Good	Good
	Sadechaf	TPA1176	Good	Good	Good
Hotmelt	3M	AHS2070	Poor	Poor	Good
	BOSTIK	H9438	Poor	Good(treatment)	Good (treatment)
Urethane	3M	DP63190NS	Good	Good	Good
	BOSTIK	PU 20102	Poor	Good (plasma)	Good (plasma)
Methacrylate	Plexus	MA8110	Good	Good	Good
	BOSTIK	SAF Ultimate 10	Medium	Poor	Poor
Silicone	DOW	Dowsil 7091	Good	Good	Good
UV – Acryllic	Sadechaf	UVACRYL 2661	Good	Poor	Good
Sylil Modified Polymer	BOSTIK	ISR 70-03	Poor	Good	Poor
Epoxy	3M	DP490	Good	Good	Good

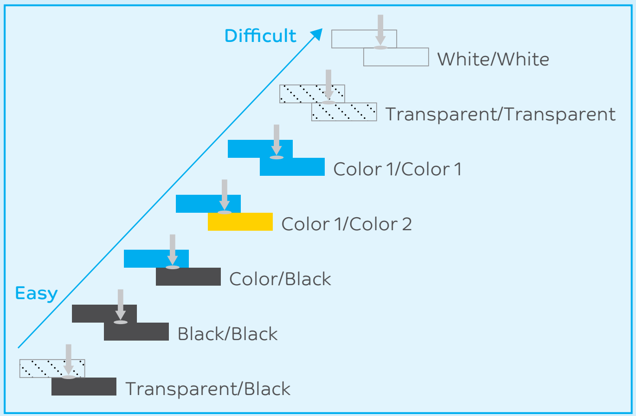
CASE STUDY:
LASER WELDABLE ELECTRONIC HOUSINGS

When considering LASER welding as assembly step it is expected come with considerable design and production advantages such as part miniaturization and increased production rate by cutting cycle times and weight out; ultimately offering more durable products. A key consideration for such devices is the polymer resin or compound of choice as well as its compatibility with the LASER absorbing substrate.

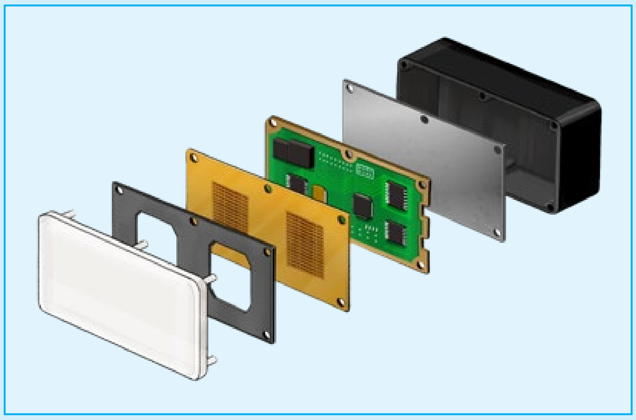
TECHNOLOGY

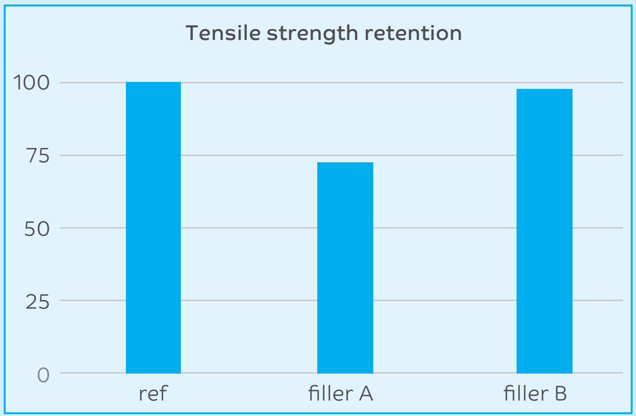
Sending a laser beam through the first layer, which is Near Infra Ted transparent to the particular light wavelength, where the second layer absorbs NIR light. The energy creates heat and melting the second layer. Layers will be clamped together, and a weld is formed.





Laser welding is applied to electronic enclosures like radar systems.





LNP™ KONDUIT™ compounds can be used for laser welding with recommended settings with slight adjustment on speed & power might be required.

TEST METHODS:
DIFFERENCE OF ISO 22007 AND ASTM E-1461

There are many different methods for measuring thermal conductivity, but transient methods typically dominate when it comes to reporting the thermal conductivity data on datasheets.

Most frequently used are the ASTME-1461/ISO22007-4 and ISO 22007-2 standards.

The ISO 22007-2 typically uses a sensor sandwiched between two plaques of the material under test. This sensor generates a heat pulse and measures the heat response of the sample and calculates both the through-plane and in-plane thermal conductivity.

The ASTM1461 uses a heat pulse and measures the temperature at the opposite side of the sample. In principle this provides only the through-plane thermal conductivity data. By cutting a plaque into strips, turning it 90° and gluing the strips together also the other direction(s) can be measured.

Using this so-called laminate method in combination with the standard measurement provides through-plane and in-plane thermal conductivity data that are quite comparable to the ones obtained with the ISO22007-2 method, using the same plaques.

This laminate method is however labor intensive, the reason why a different method has been developed for the ASTM E1461, using different samples and sample holders for measuring the through and in-plane thermal conductivity. For a good signal-to-noise ratio, thinner parts (<= 1mm) are used for the in-plane measurements and thicker samples (>1mm) for the through-plane measurements. These parts can have different orientations and can lead to higher combined through and in-plane thermal conductivity values compared to the ones found measured on one and the same sample as measured via the ISO 22007-2 method.

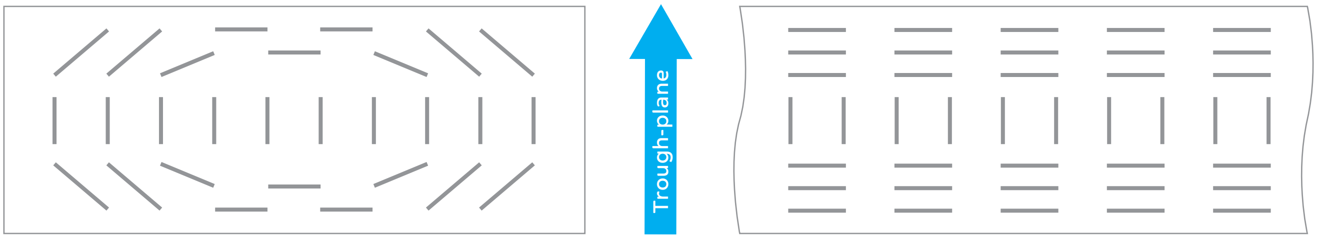
Particularly the reported datasheet values for through-plane thermal conductivity are much higher for the ASTM E1461 compared to the ISO22007-2, for similar type of materials. This mostly stems from the geometry of the part used for measuring the trough-plane thermal conductivity in ASTM E1461.

The overall orientation when using a cut impact bar is different compared to the orientation of a part cut out from the center of an injection molded plaque (see figure). The latter has lower overall orientation of the thermally conductive platelet fillers in the through-plane direction and will as a result give lower through-plane thermal conductivities.

This complicates direct comparison based on datasheet values. The through-plane thermal conductivity data measured using ASTM E1461 can be considered as a kind of upper bound. Based on extensive studies, the ISO 22007-2 data seem to better predict the thermal management for injection molded housings, as the orientation in the housings and the plaques used are more reminiscent of each other.

Orientation in x-section of an impact bar

Orientation in x-section at center of plaque



ASTM E-1461
- When considering LASER welding as assembly step According Netzsch NanoFlash (LFA447)
- Measures diffusivity (a) and Cp
- TC is calculated by: TC = a x Cp x r
- Cp determined according Pyroceram reference
- Graphite coating applied
- Different samples used for through and in-plane
- Inhouse capabilities in NL & CHN

ISO 22007-2
- According to HotDisk (TPS2500)
- Measures TC directly
- Measures in-plane, through-plane on the same sample (Cp required for anistropic samples)
- Variable geometries (e.g. color plaques, real-life parts)
- Inhouse capabilities in NL

It is recommended to compare ASTM to ASTM or ISO to ISO values. ISO values provide data, which are closer to the application (or are more reminiscent of thermal conductivity values found in true applications)

LNP™ KONDUIT™ COMPOUND PROPERTY PROFILES

	Unit	Method	PX: PA6 BASED				
			KONDUIT PX11311U	KONDUIT PX13322	KONDUIT PX11313	KONDUIT PX13012	KONDUIT PX10323
MECHANICAL							
Tensile Stress,	MPa	ASTM D 638	103	77	98	68	70
Tensile Strain,Br	%	ASTM D 638	1,8	0,7	1,3	1,2	0,9
Tensile Modulus, 50 mm/min	MPa	ASTM D 638	-	-	-	-	10750
Tensile Modulus, 5 mm/min	MPa	ASTM D 638	11842	13700	13280	10350	-
Flexural Stress	MPa	ASTM D 790	145	127	176	119	95
Flexural Modulus, 1.3 mm/min, 50 mm span	MPa	ASTM D 790	7620	11000	12500	11800	14200
Tensile Stress, break	MPa	ISO 527	105	78	108	75	73
Tensile Strain, break	%	ISO 528	1,7	0,8	1,3	1,1	0,8
Flexural Stress	MPa	ISO 178	170	128	186	105	96
Flexural modulus	MPa	ISO 178	11000	12000	13000	12000	14300
IMPACT							
Izod Impact, unnotched,23°C	J/m	ASTM D 4812	459	235	326	152	73
Izod Impact, notched, 23°C	J/m	ASTM D 256	33	21	30	15	30
Izod Impact, notched, 23°C	kJ/m	ISO 180 1A	3	3	3	3	3
THERMAL							
HDT, 1.82 MPa, 6.4 mm, unannealed	°C	ASTM D 648	193	174	215	137	186
CTE, -40°C to 40°C, flow	1/°C	ASTM E 831	3,08E-05	-	-	3,30E-05	1,61E-0,5
CTE, -40°C to 40°C, xflow	1/°C	ASTM E 831	4,77E-05	-	-	4,40E-05	3,56E-0,5
CTE, 40°C to 120°C, flow	1/°C	ASTM E 831		-	4,05E-05	-	-
CTE, 40°C to 120°C, xflow	1/°C	ASTM E 831		-	8,54E-05	-	-
CTE-Avg (-40-120C) flow	1/°C			2,95E-05		-	-
CTE-Avg (-40-120C) xflow	1/°C			5,25E-05		-	-
Thermal Conductivity through-plane, 10*10*3mm	W/m-K	ASTM E 1461-07		1,8	1,4	-	3,5
Thermal conductivity in-plane, ø25*0.4mm disc	W/m-K	ASTM E 1461-07		3,4	1,8	-	15
Thermal Conductivity through-plane	W/m-K	ISO 22007-2	1,1	1	0,9	1,2	1,5
Thermal Conductivity in-plane	W/m-K	ISO 22007-2	1,3	3,3	1,9	5,5	18
PHYSICAL							
Density	g/cm³	ISO 1183	1,74	1,69	1,79	1,68	1,61
Mold Shrinkage, flow, 24 hrs (5)	%	ASTM D 955	0,5	0,5	0,42	0,55	0,2
Mold Shrinkage, xflow, 24 hrs (5)	%	ASTM D 955	0,7	0,55	0,58	0,65	0,22
ELECTRICAL							
Surface Resistivity	Ohm	ASTM D 257	>1.E+15	>1.E+15	>1.E+15	>10E+14	1,05E+0,6
Dielectric Strength,oil, 1 mm	kV/mm	ASTM D 149	15,9	>10	>10	7,2	
UL Recognized, 94V-0 Flame Class Rating (3)	mm	UL 94	1	1	0,8	0,8	HB
Glow Wire Flammability Index 960°C, passes at	mm	IEC 60695-2-12	01-mrt	01-mrt	01-mrt	0.8-3	1,6
Glow Wire Ignitability Temperature, 1.0 mm	°C	IEC 60695-2-13	800	800	750	750 (at 0.8mm)	825

	Unit	Method	PC BASED KONDUIT DTK22	KONDUIT OX11314	OX: PPS BASED KONDUIT OX11315	KONDUIT OX10324
MECHANICAL						
Tensile Stress,	MPa	ASTM D 638	41	44	41	49
Tensile Strain,Br	%	ASTM D 638	5	0,6	0,2	0,6
Tensile Modulus, 50 mm/min	MPa	ASTM D 638	-	-	-	-
Tensile Modulus, 5 mm/min	MPa	ASTM D 638	3830	12160	30100	13500
Flexural Stress	MPa	ASTM D 790	79	47	82	75
Flexural Modulus, 1.3 mm/min, 50 mm span	MPa	ASTM D 790	3160	11200	26500	15600
Tensile Stress, break	MPa	ISO 527	42	50	54	53
Tensile Strain, break	%	ISO 528	4,1	0,5	0,3	0,6
Flexural Stress	MPa	ISO 178	81	75	84	73
Flexural modulus	MPa	ISO 178	4180	15500	21380	13500
IMPACT						
Izod Impact, unnotched,23°C	J/m	ASTM D 4812	700	90	54	70
Izod Impact, notched, 23°C	J/m	ASTM D 256	150	25	16	24
Izod Impact, notched, 23°C	kJ/m	ISO 180 1A	13	2	1	3
THERMAL						
HDT, 1.82 MPa, 6.4 mm, unannealed	°C	ASTM D 648	121	191	242	258
CTE, -40°C to 40°C, flow	1/°C	ASTM E 831	-	-	-	1,32E-05
CTE, -40°C to 40°C, xflow	1/°C	ASTM E 831	-	-	-	2,50E-05
CTE, 40°C to 120°C, flow	1/°C	ASTM E 831	5,30E-05	2,6E-0,5	-	-
CTE, 40°C to 120°C, xflow	1/°C	ASTM E 831	8,50E-05	5,1E-0,5	-	-
CTE-Avg (-40-120C) flow	1/°C		-	-	-	
CTE-Avg (-40-120C) xflow	1/°C		-	-	-	
Thermal Conductivity through-plane, 10*10*3mm	W/m-K	ASTM E 1461-07	0,6	1	3,5	3,5
Thermal conductivity in-plane, ø25*0.4mm disc	W/m-K	ASTM E 1461-07	2	2,1	15	15
Thermal Conductivity through-plane	W/m-K	ISO 22007-2	0,3	0,75	-	1,3
Thermal Conductivity in-plane	W/m-K	ISO 22007-2	1,3	1,95	-	18
PHYSICAL						
Density	g/cm³	ISO 1183	1,69	1,79	1,68	1,61
Mold Shrinkage, flow, 24 hrs (5)	%	ASTM D 955	0,41	0,18	0,34	0,16
Mold Shrinkage, xflow, 24 hrs (5)	%	ASTM D 955	0,39	0,24	0,44	0,2
ELECTRICAL						
Surface Resistivity	Ohm	ASTM D 257		>1.E+15	2,40E+15	>2.5E+04
Dielectric Strength,oil, 1 mm	kV/mm	ASTM D 149		>4		
UL Recognized, 94V-0 Flame Class Rating (3)	mm	UL 94	HB	0,8	1	1,2
Glow Wire Flammability Index 960°C, passes at	mm	IEC 60695-2-12	0,8-1	01-mrt	-	-
Glow Wire Ignitability Temperature, 1.0 mm	°C	IEC 60695-2-13	875	875	-	850

GLOBAL SUPPORT

Behind each LNP™ KONDUIT™ compound stands the extensive product and application support for which SABIC'S specialties business is well known. By optimizing the use of materials for your specific applications, this support can help you achieve even greater design flexibility and cost savings and improve time to market with differentiated product solutions.

SABIC'S Technology Centers and Global Application Technology Centers in Bangalore, Bergen-op-Zoom, Pittsfield, and Shanghai are offering a range of services, from prototype development to secondary operations to help customers validate parts designs on production-scale equipment. In addition, SABIC'S global T&I Centers offer application development support including:

Available resources include:

- Thermal simulation support, considering different design scenarios
- Design ideation for best possible thermal transfer, considering properties of thermally conductive materials and increased design freedom vs metal
- Environmental simulation, including heat aging
- Dedicated tools for testing at SABIC facilities, including ADAS demonstrator
- Full range of secondary operations capabilities at SABIC facilities
- Real part testing at our testing labs (thermal conductivity, thermal shock, aging, etc.)
- Virtual customer sessions

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