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A174

Oven

Thermotron industrial oven

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Relevant Class	Equipment
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Factory Cells	• Thermal transformation
Prerequisites	• Convection • Effect of equipment in a thermal management system • Heat transfer • Thermal transformation

Introduction[edit | edit source]

An oven is a thermally insulated piece of equipment that often uses hot air to apply temperature to a part. It is typically used for thermal transformation of parts, either on its own as the primary heating source or later in the process flow as means for post-curing. Alternatively, an oven may also be used to preheat materials for forming. The application of heat to the part functions according to the principles of convective heat transfer. This may be forced convection if the oven contains a fan for blowing hot air or natural convection if the oven simply contains heating elements that heat stagnant air. Both thermosets and thermoplastics may be cured, crystallized, or preheated in an oven.

Scope[edit | edit source]

This page provides general information on ovens as devices for heating materials, whether for thermal transformation or preforming. This includes, properties, use, safety, and supplier information. If specific information regarding brands of hot presses is desired, it is best to contact a supplier. To find information on suppliers, see the section below or navigate to the resources page.

Significance[edit | edit source]

Ovens are common pieces of equipment in composite manufacturing factories. Along with autoclaves and hot presses, ovens are one of the primary pieces of equipment used in high-temperature processing of composites. Furthermore, ovens may be found throughout the factory, from benchtop testing setups to large walk-in ovens for thermal transformation. Understanding the properties of such equipment allows for one to understand their function as part of a thermal system. Moreover, purchasing an oven may be a significant investment and requires that the customer is well-informed.

Prerequisites[edit | edit source]

Recommended documents to review before, or in parallel with this document:

- Thermal transformation
- Heat transfer
- Convection
- Effect of equipment in a thermal management system

Overview[edit | edit source]

Oven with air being blown side to side


Oven with air being blown top down

Conventional industrial ovens use fans to blow hot air in order to heat a part through forced convection. Such ovens may be referred to simply as convection ovens. It is also possible to purchase ovens that use natural convection. That is, heating elements heat the air without any fan to disperse the warm air. Instead, as the air heats up, natural convection currents are induced. For both natural and forced convection ovens, heating the air is usually done electrically by means of resistance heating. However, alternatives to resistance heating exist. These may include induction, infrared, microwave, gas, oil, and steam heating. Other radiation and vapour curing ovens also exist, where thermoset materials are cured by other means of energy than heat [1]. The use of these ovens may vary dramatically and are not necessarily restricted to thermal transformation or preheating of composite materials. For example, an oven may be used to strip coating off of a part by heating the coating to a high temperature to in order to degrade it[1]. A more familiar example of an oven's use is in cooking or baking food. While a kitchen oven may not meet the specifications of a given manufacturing factory, they operate on the same principle as industrial ovens - application of heat by convection (forced or natural) in a thermally insulated environment.

The primary difference between an oven and an autoclave is that an oven does not apply external pressure. Therefore, the maximum pressure that can act on the part is atmospheric pressure (101 kPa or 14.7 psi at sea level) and requires that the part be held under vacuum. At higher elevations atmospheric pressure drops and therefore so does the maximum potential pressure that can be applied to the part. Moreover, because an oven is not pressurized, the heat transfer coefficient is lower as compared with an autoclave. Typical HTC values in an oven are on the order of 15-50 W/m^2K[2][3] depending on air velocity, temperature, type of oven, part shape, location in the oven, and air density. For air speeds around 1 m/s, the HTC may approach 5 W/m^2K for flat panels[4]. At an air speed of 15 m/s, the HTC is closer to 40-45 W/m^2K for flat panels subject to temperatures of 100-180°C respectively[4]. Under extreme conditions with high temperature, high air velocity, and optimum part shape it's possible to bring the HTC to 250 W/m^2K[5]. However, this is unrealistic for most composite manufacturing applications.

For example, the images on the left show two different industrial ovens. One, where lateral flow adjusters are used to distribute air side to side. The other, where the fan is situated on the top, blowing air down. With these two ovens, a part placed in the same position in each oven may not experience the same HTC due to the manner of airflow distribution. It is important to consider the direction and distribution of airflow when placing parts in the oven in order to ensure good airflow over the tool-part assembly.

Depending on the oven, a vacuum system may be built in or it may have access ports for use with an external vacuum pump. Since an oven is not pressurized, these ports do not need to be hermetically sealed as they would in an autoclave. Similarly, thermocouple or other data measurement ports may be built into the oven for in-situ measurements or, alternatively, open access ports may be used to run external sensors into and out of the oven during operation.

A furnace operates on the same principles as an oven and the two terms are often interchanged. The primary difference is that furnaces operate to much higher temperatures. Traditionally, ovens operate below 538°C (1000°F) and furnaces up to 1100°C (2000°F), although some ovens may go to higher temperatures. Another common difference is that industrial ovens using ducting to disperse air, heated in a separate chamber, onto the part. In an industrial furnace, air is heated and dispersed in the same chamber as the part[6]. Other differences include the construction and insulation of the equipment. An environmental chamber is another piece of equipment that functions similar to an oven. The difference is that environmental chambers also control humidity.

Properties[edit | edit source]

Heating	Temperature	Pressure	Vacuum
Typically convective heating - usually forced. HTC ~ 15-50 W/m^2K[2][3]. This range is generally accurate for flat panels subject to air speeds of 3-15 m/s and temperatures of 100-180°C[4]. At air speeds of 1-3 m/s, the HTC may be closer to 5-15 W/m^2K[4].	Typical temperature range: 20°C (68°F) $\leq$ T $\leq$ 538°C (1000°F)[6].	No pressure control. P_{app} = 0.	Internal or external vacuum control possible. P_{vac} = -101 kPa (-14.7 psi) at sea level.

Typical specifications[edit | edit source]

Example oven[7]

Manufacturer	Equipment series	Working fluid	Heating mode	Cooling mode
Thermal Product Solutions (TPS)	Blue M 146 series standard mechanical convection oven	Air	Electric	Air

Example oven specifications[7]

Max temperature	Min temperature	Control accuracy	Resolution	Interior volume	Footprint
350°C	Room temperature	+/- 1.0°C	+/- 0.1°C	0.12 - 0.68 m^3 (depending on model)	0.037 - 1.8 m^2 (depending on model)

Advantages[edit | edit source]

- Cheaper alternative to an autoclave; both the equipment itself and the tooling cost for prepreg systems[8]

- Reduced environmental impact compared with an autoclave due to lower energy consumption and cycle time reduction[8]
- Available in a range of sizes (benchtop to walk-in), allowing for accommodation of small or large parts
- Can be used as a means of thermal transformation, preheating, or other steps involving application of heat
- Useful for secondary thermal transformation steps such as post-curing
- Multiple parts can be loaded in one batch

Limitations[edit | edit source]

- No external pressure application, resulting in generally lower fibre volume fraction parts and higher porosity (on the order of 5-10%[9])
- Lower heat transfer coefficient (HTC) as compared with an autoclave; 15-50 W/m^{2}K[2][3] compared to 60-200 W/m^{2}K[4][10][11]
- Surface finish and dimensional control are not as good as compared with a hot press

Use[edit | edit source]

Ovens may be used for any purpose involving application of heat. With regards to composites manufacturing, one of the most important uses is in thermal transformation of the matrix material. That is, curing or crystallization of thermoset or thermoplastic components, respectively. A part may be thermally transformed solely in an oven or in combination with other equipment, such as a hot press. A manufacturing technique that may be employed to increase throughput is to partially cure materials in one piece of equipment and then transfer them to an oven for post-curing. This decreases the amount of time a single piece of equipment requires for thermal transformation of a given part (or batch of parts) by spreading out the curing process over several equipment. This is also reduces the limitation of ovens not having external pressure application, as consolidation of the part is typically achieved prior to being transferred to the oven. Almost all materials forms can be thermally transformed in an oven. This includes materials where the fibre and resin were combined by an operator or a prepreg system where the resin and fibre come pre-combined by the material manufacturer. In the latter case, such materials are often referred to as out-of-autoclave (OoA) prepregs. This is because, traditionally, thermoset prepregs have been processed in an autoclave to achieve the necessary consolidation, porosity reduction, and fibre volume fraction. However, recent advancements have allowed for autoclave-quality prepreg parts to be processed under vacuum-bag-only (VBO) pressure[8]. Typically such materials are processed in an oven, as the heating source for thermal transformation. That said, OoA prepregs may be thermally transformed using other non-autoclave setups such as a hot press or heated blanket. In the aerospace industry, it has been proposed that VBO prepregs allow for the installation of parallel production lines where an autoclave is replaced by several ovens[8]. With regards to non-prepregs, ovens are commonly used for thermal transformation of parts where material deposition was done by means of resin infusion, wet layup, spray up[9][12], filament winding[9][13], or other process steps. Finally, cold moulding of thermosets is another process step where an oven is used for thermal transformation. In this process, powder or filler material is mixed with a binding agent and shaped in a die, where it is then transferred to an oven for curing[12].

Another important use of an oven is in preheating the material/part for forming. The part may be placed in an oven in order to reduce its viscosity and/or bring it to its melting temperature (for thermoplastics), to allow the material to flow more easily. Once the part has reached the intended temperature, it may then be transferred to another piece of equipment (such as a press) for forming.

The heating process may be continuous, where charges (parts prior to forming) are placed on a conveyor belt and then move through a convection or infrared oven. Once out of the oven, the charges are transferred by hand or robot to the forming tool[14].

Hot debulking of thermoset prepreg plies is another process step that may utilize an oven. In such a scenario, a few plies are laid down at a time, transferred to an oven, and put under vacuum[9]. This allows for water vapour, alcohol, and other volatiles to come out of solution by raising them above their boiling temperature. The vacuum will then draw the volatiles out of the material. One problem with this method of hot debulking is that it's costly and labour intensive since the layup is constantly being interrupted, bagged, put in an oven, debulked, and then cooled before more plies are laid down[9]. Another method is to apply a slow heating rate in the oven with intermediate isothermal holds under vacuum, to ensure that any volatiles coming out of solution are removed during cure[9]. Hot debulking is especially important for condensation curing systems such as polyimides and phenolic resins which give off water and alcohol during cure. A hot debulk can also be achieved in a hot press or autoclave, with slightly different methodologies.

Other uses of ovens may include heating composite tools, cores, or other materials to remove their moisture content[9]. Overtime, composite tools and other components in room-temperature storage may absorb moisture. Drying these components prior to use is important in order to prevent blistering or bubble growth in the part during thermal transformation.

Applications[edit | edit source]

Ovens are common pieces of equipment in composite manufacturing factories and are found in most industries, including:

- Automotive
- Aerospace
- Sporting goods
- Construction
- Consumer products
- Others

Safety[edit | edit source]

NOTE: This safety information is not comprehensive, and is only intended to draw the reader's attention to some important safety considerations. The reader should be refer to applicable safety data sheets (SDS) and manufacturer instructions.

Ovens are generally simple pieces of equipment to operate. The main hazard is burns due to the high temperature. Operators should not touch any surfaces while they are hot. Similarly, the oven should not be opened while the temperature is high. Not only is this a safety concern, but it will also influence the heating cycle and may result in unexpected outcomes. After a heating cycle, sufficient time should be allowed for the oven to cool down before it is opened. Temperature readings from the controller or from operator-placed thermocouples can be used to indicate when the oven is safe to open.

Proper PPE should be worn when operating the oven. This may include a face shield, heat resistant gloves, heat resistant coveralls, and steel-toed boots. It is especially important to wear heat resistant gloves when removing items from the oven as the part(s) and tooling may still be hot. It is good practice to have a spotter present in the event of an emergency. The space around the oven should also be kept clear to avoid dropping heavy and/or hot items, especially when transferring parts and tools from other areas of the factory. Steel-toed boots should always be worn on the shop floor, especially if dealing with heavy items.

Key considerations during use[edit | edit source]

Storage & Handling[edit | edit source]

When running a cycle, ensure that any vacuum lines that are not in use are switched off. Also ensure that no unintended items are in the oven before starting a run. Aside from safety concerns, unintended items may influence the thermal response of the system leading to unexpected outcomes. Finally, check that the door is properly closed and locked before beginning the cycle. For many industrial ovens, the heating cycle won't start if the oven is not closed properly. Similarly, if the oven is opened during operation, the cycle often pauses, resuming once the door is closed again. Once the run is over, ensure that the temperature cycle has ended and the power controller is switched off. Any water cooling valves should be closed.

Cleaning[edit | edit source]

The workspace surrounding the oven should be kept clean. This ensures a safe work environment. All material spills should be handled to according to appropriate spill safety procedures.

Preventative Maintenance[edit | edit source]

Servicing and calibration should be done according to the manufacturer recommendations. All maintenance should be carried out by experienced individuals and/or contractors from the manufacturer.

Suppliers[edit | edit source]

Product suppliers[edit | edit source]

Common providers of this equipment include:

- Thermal Product Solutions (TPS)
- ASC Process Systems
- Thermotron
- Eastman Manufacturing Inc.
- Wisconsin Oven
- SAT Industrial Thermal Equipments
- LEWCO
- Despatch
- Baker Furnace Inc.

For additional suppliers, visit the following webpage[15]:

https://www.compositesworld.com/suppliers/product/386

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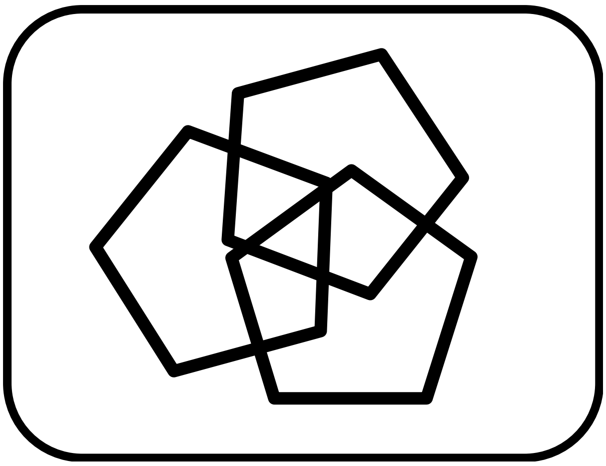

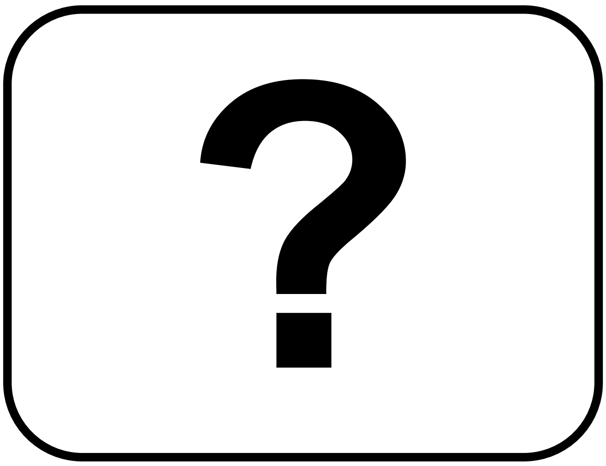

About **Help**

'Preforming' refers to the task of preparing the fibre.

- Cutting it out
- Assembling a number of pieces (stitching, bonding, etc.)
- Forming on a (heated) tool

Engineered materials (designed to have specific properties) made from two or more constituent materials with different physical or chemical properties. The constituents remain separate and distinct on a macroscopic level within the finished structure.

Thermosets are a class of polymer that undergo polymerization and crosslinking during curing with the aid of a hardening agent and heating or promoter. Initially they behave like a viscous fluid. During curing, they change from viscous fluid to rubbery gel (viscoelastic material) and finally glassy solid.

If heated after curing, initially they become soft and rubbery at high temperatures. If further heated, they do not melt but decompose (burn)

Comes in two parts: part A (resin) and B (hardener). When mixed, curing reaction starts and is not reversible.

Examples include epoxy or polyester.

Pre-impregnated (prepreg) material refers to fibre that is already combined with resin. It is the most common material form used in aerospace.

During prepreg production, (e.g. fibres are run through a resin bath), prepreg is heated and partially cured to B Stage (< 5 % degree of cure). Thermoset prepregs (e.g. epoxy prepreg) have to be kept in a freezer at around -20 °C. At room temperature, the epoxy starts to cure.

Volume fraction of either matrix or fibres with respect to total composite volume (matrix + fibre).

The continuous material phase that binds the reinforcement together, maintains shape, transfers load, protects the reinforcement from environment and damage, and provides the composite support in compression.

Desirable characteristics:

- Moisture/chemical resistance
- Low density
- Processability

A class of polymer, some common examples include polypropylene and polyethylene.

They soften and melt upon heating (i.e. potentially recyclable), high viscosity when melted, therefore difficult to saturate fibres. Usually needs a lot of pressure and heat to process.

For polymer matrix composites (PMCs), resin refers to the matrix; the continuous material phase that binds the reinforcement together, maintains shape, and transfers load. Resins are divided into two main groups: thermosets and thermoplastics.

A single unit of fibre reinforcement that cannot be separated further without breaking it. It often has a circular cross section that is formed by the dies used to create it or its precursor material. Many filaments are manufactured in parallel to produce a strand or tow. The number of filaments in a strand or tow is often references by how many thousands of filaments comprise the tow. e.g. an 18k tow is made up of ~18000 filaments.

In composites processing, viscosity is an indicator of how easily the resin matrix will mix with the reinforcement and how well it will stay in place during processing. The lower the viscosity, the more easily resin flows. Resin viscosity ranges considerably across chemistries and formulations.

By scientific definition, viscosity is a measure of a material’s resistance to deformation. For liquids, it is in response to imposed shear stresses.

An acronym that stands for Safety Data Sheet. These are documents that provide information about safety precautions and hazards of a product. They are typically provided by the product manufacturer. Different jurisdictions have different legal requirements for these documents.

Any manufacturing and/or decision making activity that occurs during any stage of the development design cycle (e.g. conceptual design to production).

In the context of Knowledge in Practice, practice refers to the systematic use of science based knowledge to reduce composites manufacturing risk, cost, and development time.