# Sintered Wire Mesh

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***"A sintered laminate is a new material, different from its component layers; and the whole becomes more than the sum of its parts."***

Synopsis

The properties of woven wire cloth may be enhanced by a process loosely referred to as "sintering," which depends upon molecular diffusion-bonding. The same process may also be used to laminate multiple layers of wire cloth together, thereby creating a diverse and highly useful class of permeable materials that is still not widely known within the engineering community. Sintered wire mesh laminates may be designed with a wide range of desirable mechanical properties, pore sizes and controlled permeabilities, and have found their way into many different applications. This article discusses the sintering process, wire mesh, and sintered wire laminates, including a discussion of applications, fabrication of these materials, and technical and metallurgical considerations.

## What is sintering?

Sintering may be defined as a thermal process that induces diffusion bonds. The sintering process bonds together tangent metal surfaces at their points of contact without the addition of any filler metal or bonding agent. A suitable environment of high temperature and isostatic pressure causes this bonding to occur via a combination of various mechanisms, including surface and volume molecular diffusion, evaporation and recondensation, grain growth and recrystallization, deformation and plastic flow.

In a proper sintering process, these mechanisms work together to produce a securely fused joint at each metal-to-metal contact point. Such a process may be used to sinter together metal powders, fibers, wires, and fine screens to create a wide variety of materials, as well as laminating such materials to coarser support structures such as perforated plate, solid or photo-etched metal foils, expanded metal, or heavy structural wire meshes. This article will focus primarily on the class of structures produced by sintering multiple layers of woven wire mesh together to create an integrally bonded laminate.

An important point is that in almost all cases, the solidus (melting point) of the alloy is not exceeded during sintering, and no incipient melting is permitted. So, for example, in Federal Specification SE-F-0044 (Filters, Wire Cloth Type, Space Shuttle Program), the definition of sintering as "a process whereby woven wire is partially melted to cause bonding…" is simply incorrect.

What is wire mesh?

Wire mesh is a metallic woven fabric manufactured by weaving drawn metal wires together on a suitably designed loom. The basic process is similar in concept to that of weaving cloth fabrics. Meshes are typically woven with wires running in two perpendicular directions, and are produced in roll form. A typical commercial roll of wire mesh might be 36" or 48" wide x 100 feet long. In some cases, meshes are woven as narrow as 3" wide or more than ten feet wide (e.g. for use in the Fourdrinier process in the paper and pulp industry).

The wires running the full length of the roll are called "warp" wires, while those running across the width of the roll are variously known as "weft," "fill," or "shute" wires. The "warp count" is the number of warp wires per inch of roll width, and the "fill count" is the number of weft wires per inch of roll length. If the warp count is 12 and the fill count is 64, the "mesh count" is denoted 12x64.

If the warp count equals the fill count, i.e. the same number of wires run in both directions, then the mesh is said to be "square." For example, if 100 wires per inch run in both directions, then the mesh count is 100x100. This is generally referred to as "100 mesh," implying a square weave. Square weaves are woven from 1x1 mesh to 635x635 mesh. The 635 mesh uses wires .0008" diameter and has 25 micron square apertures. This ultrafine screen usually costs about $200 per square foot. Square meshes are most commonly used as sieves or sifting media in simple filtration, separation and classification, but are also used in a myriad of other applications.

If the warp count is substantially different from the fill count, the mesh is said to be a "Dutch" or "Hollander" weave. The 12x64 mesh referred to above is a standard Dutch weave specification, with .024" warp wires and .0165" shute wires. This is a rugged yet very permeable material that is particularly useful in filter presses, dewatering, and is incorporated into many designs of sintered laminates.

Weaves may also be "plain" or "twilled." In a plain weave, the wires cross "over one, under one" in the mesh, while in a twill weave they cross "over two, under two." Twilled weaves allow the use of heavier wires for a given mesh count, or higher mesh counts for a given wire diameter. Thus most coarse square and Dutch weaves are plain weaves (i.e. plain square weave, or plain Dutch weave), while many of the finer meshes are twilled.

The finest meshes produced are twilled Dutch weaves such as 325x2300 mesh, 400x2800 mesh, and 510x3600 mesh. The latter material costs about $200 per square foot, and is effective as a filter medium at removal ratings of five microns or less. A modern automatic weaving loom can produce only several linear inches per hour of this mesh, as the bobbin which threads the fill wires must "shuttle" back and forth 1800 times per linear inch of mesh to produce a fill count of 3600 wires per inch.

Wire meshes may be woven in a variety of metals and alloys. The base material must be capable of being drawn into a fine wire with enough ductility and strength to survive the weaving process. Typical materials suitable for weaving include plain steel, 300 Series stainless steels (e.g. 304, 304L, 310, 316, 316L, 347), 430 stainless, copper, brasses and bronzes, titanium, and nickel and its alloys. The latter group includes such useful materials as Monel, Inconel and the Hastelloy alloys.

A full description of a wire mesh must include the mesh count, wire diameters, weave type, and alloy. For example, "12x64 mesh, .024x.0165" wire diameters, plain Dutch weave, AISI type 316L stainless steel" is a proper wire mesh specification.

## Why sinter wire mesh?

Sintering may be performed on most types of woven wire mesh. The principal reason to sinter a woven wire mesh is to bond all the wires where they cross, thus eliminating medium migration. As-woven meshes are generally prone to edge fraying. A square inch of 100 mesh contains 200 wire strands touching at 10,000 contact points -- too many to bond one at a time by any other process!! However, if properly sintered, virtually every point will become securely fused. Even small discs may then be punched from the cloth without any fraying. This is critical in so many applications, such as medical filtration or aircraft hydraulic fluid filtration, in which loose wires could cause catastrophic failure. In addition, the mesh geometry becomes permanently fixed once the wires are fused in place. Wires cannot be shifted under pressure, and the aperture size therefore remains stable in service.

The sintering process is also a heat-treating process. If the process atmosphere and cycle are suitably controlled, the wire cloth is rendered bright and clean, fully ductile and metallurgically solution annealed. Despite the annealing, overall tensile strength is improved in most weaves due to the bonding between the wires. Thermal and electrical conductivity are increased. Formability and ductility are markedly improved, including the ability to retain shapes and hold pleats.

Wire mesh is not properly sintered if the bonds are very weak; or if only a small number of intersections are adequately bonded; or if wires therein fray too readily. Too often the term "sintered" is applied to wire mesh that is merely annealed in coil or roll form. If the annealing time and temperature have been increased, the process may provide some sintering effects. The results may be good enough for a given end use, but this process should be called "super-annealing" or "semi-sintering," to distinguish it from a true sintering process. In their favor, these simple roll-annealing processes are much more economical than true sintering. However, product liability costs resulting when improperly bonded wires fray in critical applications will often justify using a higher-cost true sintered material in critical applications.

Another chief purpose and benefit of the sintering process is to create new structures by laminating multiple layers of wire cloth together into laminates or composites of many varieties. A sintered laminate is a new material, different from its component layers; and the whole becomes more than the sum of its parts. Let's examine some of the many types of laminates.

## Sintered Wire Mesh Laminates

Consider a fine micron-rated filter mesh, which provides a desired pore size. For example, a 325x2300 mesh, .0014"x.0010" wire diameter, twilled Dutch weave, has apertures of less than 10-12 microns, but is only .003" thick. This expensive but flimsy and easily damaged material may have useful characteristics provided by its fine pore structure, but it also has poor mechanical properties. *The solution:* laminate the fine screen to a coarser mesh backup layer to provide strength, support and thickness. The resultant two-layer laminate retains the filtration rating of the fine layer, and the mechanical properties of the coarser support layer. This combination of properties would not be available from any single woven mesh. *Applications: filtration, sifting, screening, air intake protection, dust barriers, sparging.*

Extending this principle, various structures may be created employing one layer of micron-rated filter mesh (or other fine wire screen, such as a sieve mesh) in combination with multiple layers of coarser meshes. The fine mesh may be sandwiched between protective layers to form a symmetrical structure. *Applications: bi-directional filtration media, hydraulic valve screens.*

Similarly, filter meshes used in pleated filter elements may benefit strongly from being laminated between two layers of coarser meshes. On the downstream side, a backup layer imparts strength and serves as a spacer to prevent "closing off" of pleats. On the upstream side, an outer layer provides mechanical protection, and similarly aids in preventing closing off. By sandwiching the fine mesh between two layers, it is subjected to less stress during pleating. As the wires within the mesh are also sintered, the pore size will resist deformation at the peaks and valleys of the pleats. The advantages of pleatable sintered laminates in the manufacture of filter elements were the driving force behind the development of sintered wire mesh over four decades ago. *Applications: process filtration, high-quality hydraulic fluid filters.*

A fine mesh may also be laminated to the surface of an arbitrarily thick and strong support structure containing any number of layers of heavy support meshes, or to a perforated or expanded metal plate. *Applications: Nutsche filter-driers, filter presses, chromatography frits, large-area filter plates, centrifuges.*

Alternatively, the fine screen may be laminated to a thin-gauge solid or perforated metal foil, or a photo-etched foil. *Applications: heat pipes, fuel cells, ion traps, coffee filters, acoustic treatment of combustion chambers and APU inlets.*

A particularly useful and widely employed filter plate may be created by sandwiching the fine filter mesh between two layers of medium square mesh screens, then laminating this sandwich to a strong base comprising two or more layers of either square meshes or the previously mentioned 12x64 structural support mesh. The first layer of medium square mesh provides protection to the filter mesh, which in turn provides a desired pore size. Another layer of square mesh provides some internal flow distribution volume, and acts as a buffer zone between the filter layer and the heavy support layers. Like many laminates, this material may be used flat or rolled and welded to form tubular elements. *Applications: polymer filtration, Nutsche filter presses, pharmaceutical processing, gas sparging, beverage filtration and clarification, fluidized beds.*

Even a medium to coarse square mesh, which may have good mechanical strength on its own, may be bonded to still coarser meshes for additional mechanical strength where required. Such laminates are nonetheless ductile and formable, and may even be substantially deformed into various deep drawn mold shapes. *Applications: high-pressure and high-volume pre-filtration, pulp forming molds for egg cartons, apple trays, and molded paper plates; vacuum dryers.*

Frame-bound or spot-welded “screenpacks” with many layers of square weaves are commonly used in polymer production as well as a variety of other applications in which a fluid passes through the pack. Typically these may be designed with “graded density,” i.e. a progression of coarser to finer screen sizes within the pack. When such multiple-layer packs are sintered together, the resulting laminate takes on a completely different and superior character as compared with a frame-bound or spot-welded pack. Some of these advantages are as follows:

- Mechanical Strength

  The sintered pack exhibits much greater strength and rigidity than an unsintered pack. This means the pack can withstand higher pressures and throughputs without deflecting or dishing. Freedom from deflection means more uniform flow across the pack surface without “peaking” in the center.

- Structural Integrity

  The sintered pack will be completely free from medium migration. No wire fragments can come loose and cause damage downstream. Sintering eliminates separation between the pack layers, and any resultant lateral flow channels. Residence time of the filtrate is decreased, and throughput is increased. For viscous fluids such as molten polymers, shear is imparted more uniformly to the filtrate as the pack remains rigid.

- Maintenance of Filtration Rating

  The wires in conventional unsintered meshes tend to shift and separate as solids are forced through them under pressure. The result is that some of the pores may open up. Conversely, in a sintered pack, the wires in each layer of mesh are securely fused together and will not shift. Therefore the micron rating and bubble point of the pack will remain constant throughout up over time, and the filtration integrity of the pack is not compromised.

- Cleanability

  Sintered wire mesh packs can withstand many cleaning processes some of which would destroy conventional packs, including high-pressure washing, steam cleaning and autoclaving, oven burn-off and furnace firing, caustic baths, passivation baths, solvent cleaning, ultrasonic cleaning and other processes used by professional filter cleaning companies.

Extending the principle of sinter-bonded screenpacks, a remarkable class of materials can be manufactured by laminating even greater numbers of layers of square weaves together to produce materials ¼", ½" or even several inches thick. For example, multiple layers of the same weave at varying angular orientations, or alternating layers of several different weaves, may be laminated in sequence in a highly repeatable fashion. Such materials exhibit high surface area and thermal capacity, shock absorption capability, and mechanical strength, and may be useful in a variety of applications involving high-speed, high-temperature gas flow. These materials can be produced with controlled void volumes (sometimes loosely referred to as "porosity") of up to 80% void. *Applications: regenerators for Stirling cycle engines and cryo-coolers; flame, spark and detonation arrest media.*

Laminates of two or more layers of heavier Dutch weave meshes such as 12x64 and 24x110 are remarkably strong and rigid, even more so than the above described square weave structures. Furthermore, these materials may be densified by calendering (i.e. compacted by passing the sheets through a vertical rolling mill) until a desired permeability to flow is achieved. These plate-like structures form the cornerstone of another whole class of materials that are produced to a controlled permeability to flow, rather than to a specific pore size. *Applications: flow snubbers, flow restrictors, transpiration cooling, liquid rocket fuel injection, controlled combustion infrared sources, flow conditioning and attenuation in supersonic airstreams, detonation arrest, acoustic silencing.*

Incorporating a high-density twilled mesh into the above plate-like controlled permeability laminates, one can produce media which permit controlled air flow down to 100, 10 or 1.0 SCFM per square foot at a pressure drop of 2" water column. Such materials are highly useful in the handling of bulk dry solids. Just as an air hockey puck floats smoothly across the surface of an air hockey table on a bed of rising air, so too can bulk tonnage of dry powders such as cement, calcined alumina, fly ash, diatomaceous earth, flour, or PTA (purified terephthalic acid) flow smoothly on "fluidized" conveyors lined with controlled permeability laminates. A pressurized plenum beneath the laminate provides a steady airstream, which lifts and aerates the dry solids, allowing ready flow. This technology may also be incorporated into silos, hoppers, truck and railcar discharges, and bagging and filling equipment.

These are only some of the many possible structures available in sintered wire mesh laminates. Custom laminates may be produced with specific pore sizes, permeability to flow, void volume, mechanical strength, thickness, and alloy to meet these applications and undoubtedly many more which have not even been developed yet.

## Fabricating with Laminates

The materials described above may be fabricated with a wide variety of standard sheet-metal techniques, including blanking, punching, shearing, braking, and forming. Laser cutting, water jet cutting, and wire EDM have proven very useful in cutting parts from sheet stock. A variety of welding techniques may also be employed.

It is therefore possible to offer flat discs, irregular shapes, molded and formed parts, rolled and welded tubes, cones and conical segments, large area discs, and a variety of other components. While some precautions may need to be developed in order to protect fine porous surfaces, these materials are generally easy to work with.

## Quality and manufacturing considerations

There are several useful and informative specifications covering woven wire mesh, such as ISO 9044 (Industrial woven wire cloth – Technical requirements and testing), and ASTM E2016-99 (Standard specification for Industrial Woven Wire Cloth). However, there is no federal or military specification covering the sintering process, sintered wire mesh, or sintered wire mesh laminates.

Generic heat treating specifications such as MIL-H-6875 provide valuable guidelines for process control and equipment calibration, but have no specific bearing on sintering. This lack of specifications has led to a proliferation of practices called “sintering”. The key feature of sintering is the bonding between the wires of each mesh, and between the layers of a laminate. Any sintering process must be evaluated in terms of bond strength, as well as good metallurgical practice.

True sintering requires very high temperatures and the application of uniform pressure normal to the plane of the mesh or laminate. This is typically achieved by processing the material in flat rectangular sheets. However, in some applications, longer seamless lengths are required; while in other applications, continuous strip or coil might be desirable for subsequent fabrication such as stamping, pleating or spiral winding. To accommodate this need, various processes have also been developed to sinter wire mesh (or to laminate two or more layers of mesh) in longer length strip. These processes may be continuous, or they may be modified batch processes.

A truly continuous sintering process is a dynamic process wherein the meshes are unwound, are fed continuously into a furnace, are thereby sintered, and are then rewound after exiting the furnace. This is similar in principle to a continuous linear strip annealing process. Alternatively, a modified batch process may be employed to create a long-length laminate strip or coil. For example, materials are sometimes wound up into a coil with a suitable separation medium interleaved. Either of these processes are well-suited to sintering wire mesh in single layers, to induce bonding at the wire intersections.

The above processes may also be employed to create a multi-layer laminate, as long as the setup induces sufficient compressive pressure normal to the plane of the laminate. For example, it is possible to produce a true sintered laminate in continuous form if compressive force can be applied to the moving strip, e.g. by hot calendering rolls in the sintering furnace. It is also possible to produce a true sintered laminate in coil form if the wind-up procedure incorporates sufficient tension to result in a radial component of compressive force. In a different method, the component layers may be folded over repeatedly, so as to simulate a stack of sheets. Like continuous coiling, this method allows the placement of longer seamless lengths of material into a finite-sized batch furnace. No matter what form the process takes, there must be an adequately engineered technology to produce a consistent, well-bonded product.

## Additional Metallurgical Considerations

Process conditions, including furnace atmosphere and residual contaminants, may adversely affect metallurgical properties. If the mesh is 300 Series stainless, its corrosion resistance can be impaired by poor practices leading to carbide precipitation, chromium depletion and other problems. Austenitic stainless steels may also be adversely impacted by furnace contamination, cooling rates, and absorption of carbon from hydrocarbon lubricants used during the weaving process.

Experience with the process is the best prevention. Properly processed 300 series stainless should be capable of meeting the required carbon content limits, and passing an accelerated corrosion test to verify freedom from susceptibility to intergranular attack (e.g. the "Strauss Test" per ASTM A262, Practice "E").

In order to prevent the laminate from sintering to furnace hardware or other sheets of laminate, some processors have interleaved various refractory materials. These materials may cause contamination, oxidation, metallurgical degradation and other problems. This problem may become severe in the processing of alloys containing reactive metals such as titanium or zirconium. In such cases, special inert materials must be employed.

Any sintered wire mesh laminate should also be capable of withstanding its intended use without delamination. This includes materials which are to be formed into small-diameter tubes or subjected to other severe deformation. Suitable bend tests maybe conducted to determine that a quality process was employed. It is preferable that the laminate be in a solution annealed condition after sintering, rather than a cold-worked condition.

## Conclusions

Sintered wire mesh laminates represent a large, diverse and highly useful class of permeable metallic media, available with a wide range of useful properties. While a great many applications for these materials have already been found, there are undoubtedly many more waiting to be developed. Engineers are encouraged to consider new ways to employ these materials to their best advantage.

### Biography

The author, Douglas L. Kurz, earned an *A.B. summa cum laude* in mathematics from Harvard College, Cambridge, MA, and a *J.D. cum laude* from the Harvard Law School. Mr. Kurz has extensive technical training in mathematics, physics and engineering. He has been actively managing Martin Kurz & Co., Inc. (“MKI”) since 1987, and has held the office of President since 1998. MKI manufactures diffusion-bonded (sintered) wire mesh laminates under the registered trademark DYNAPORE®. They are located at 138 Liberty Avenue, Mineola, NY 11501.
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