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(54) **Title:** NETWORK OF METAL FIBERS AND METHOD OF ASSEMBLING A FIBER NETWORK

(57) **Abstract:** The invention relates to a method of assembling a fiber network comprising a plurality of metal fibers, wherein the method comprises the following steps: providing a loose network out of the plurality of metal fibers at an assembling site; fixing the plurality of metal fibers to one another by forming contact points between the single metal fibers by (A) heating the plurality of fibers at a heating rate higher than 50 K/min, in particular higher than 100 K/min, especially higher than 200 K/min, preferably higher than 1000 K/min, to a fixation temperature selected in the range of 50 to 98% of their melting point temperature; (B) keeping said fixation temperature for a fixation time selected in the range of 30 seconds to 30 minutes; and (C) cooling the plurality of fibers at a cooling rate higher than 50 K/min, preferably higher than 100 K/min. The invention further relates to a network of metal fibers comprising a plurality of metal fibers fixed one to another at contact points, wherein the metal fibers non-round cross section, in particular a rectangular, quadratic, partial circular or an elliptical cross section with a large axis and a small axis, or wherein the metal fibers comprise a round cross section, and wherein the fibers comprise a width which is generally constant along a length of the fiber such that a variation of the width of the fiber along its length is less than 40%, preferably less than 30%, in particular less than 20%.

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Network of metal fibers and method of assembling a fiber network

The invention relates to a method of assembling a fiber network comprising a plurality of metal fibers as well as to a network of metal fibers.

Networks of fibers are nowadays used for a great variety of applications ranging for example from filters to batteries.

Conventionally, filtration of gases such as air or liquids is based on metal fiber meshes or foams. Such meshes or foams are nowadays part of a great variety of devices, ranging from oil filters in automotive applications to cleaning systems for fluids or gases such as air.

Conventionally known filters are usually based on metal fibers comprising a circular cross section (e. g. oil filters) or on carbon-based foams (e. g. HEPA filters). Filters made out of metal fibers with circular cross sections are characterized in that such fibers comprise a high mechanical stability while comprising small surface to volume ratios. However, such filters usually comprise a rather high weight since a great amount of fibers is needed. Filters made out of carbon foams, on the other hand, are mostly rather fragile while being light weighted and having a rather large inner surface area. Furthermore, it is noted that the filtration capacity of such conventionally known filters is not ideal.

In another application field, networks of metal fibers can also improve the performance of secondary batteries when being used as secondary electrodes. Such

networks of metal fibers can also contribute to the performance in catalytic materials in electrochemical applications such as in fuel cells and hydrolysis, or as component in electromagnetic shielding materials, as filters, in polymer composites or as tissue material and tissue hybrid material which may also include as additives, e.g. cotton, silk or wool.

Because of said great variety of different application fields, the need of being able to fabricate fiber networks with different definite characteristics depending on their application field, is enhancing.

In conventionally known processes of fabricating fiber networks, a plurality of fibers is provided in a hot press and subjected to a high pressure. Then the plurality of fibers is placed in a furnace and slowly heated up to a temperature close to the melting temperature of the fibers while the plurality of fibers still being subjected to said pressure. The high temperature is maintained until the fibers connect to one another. Afterwards, the fabricated network is slowly cooled down.

The above described process is also known as “sintering”. Such processes usually take up to one hour or more depending on the capacity of the oven used. It was now recognized that conventional sintering allows fibers to undergo relaxation before reaching temperatures high enough to connect the fibers to one another. These relaxation processes release stored energy from the fibers. As an example, fibers obtained by rapid cooling techniques, e.g. melt spinning, can have substantial amounts of stored energy.

The driving force for the above described process is the reduction of the surface of the fibers and the associated reduction in their free energy ΔG. The free energy ΔG can be divided into a surface component ΔG_S, a volume component ΔG_V and a grain boundary component ΔG_B. This relationship is described in equation (1). During the sintering of the fibers, the volume fraction remains almost constant

($\Delta G_V = 0$), while the grain boundary fraction increases due to the transformation, i.e. the reduction of the surface ($\Delta G_B > 0$), and the volume fraction decreases ($\Delta G_V < 0$). The volume part ΔG_V clearly outweighs the grain boundary part ΔG_B, which leads to a negative change in the total free energy of the system ($\Delta G < 0$) and the process takes place voluntarily as soon as a certain energy threshold (activation energy) is exceeded. During conventional sinter processes, reduction of ΔG is associated also with a rounding of the fibers, i.e. the fiber diameter transitions into a round shape, herein also referred to as rounding.

$$\Delta G_T = \Delta G_V + \Delta G_B + \Delta G_S \quad (1)$$

The energy threshold to be exceeded here is the activation energy E_A of the diffusion (equation (2)). Here D_0 is the temperature-dependent diffusion constant, k the Boltzmann constant, T the absolute temperature and D the temperature-dependent diffusion constant. The greater the temperature-dependent diffusion constant D (in $m^2\ s^{-1}$), the faster the rounding of the fibers takes place. Here, the temperature is not only responsible for fulfilling the activation energy E_A, but also the speed-determining factor.

$$D(T) = D_0 e^{-\frac{E_A}{kT}} \quad (2)$$

Such known sintering processes thus take place through a rearrangement process at the atomic level (diffusion) and not through a process with renewed melting of the fibers. The thermodynamic goal is to achieve the largest possible volume with the smallest possible surface. The perfect ratio here is achieved with a perfect sphere.

With the conventionally known methods for fabricating fiber networks this effect cannot really be controlled in order to produce, for example, fiber networks with fibers of a definite cross section.

It is therefore an object of the invention to provide a method of assembling a fiber network having increased control of the fiber cross section as well as a corresponding fiber network. This object is solved by the subject matter of the independent claims.

In particular, the present invention provides a method of assembling a fiber network, comprising a plurality of metal fibers, wherein the method comprises the following steps:

- providing a loose network out of the plurality of metal fibers at an assembling site;
- fixing the plurality of metal fibers to one another by forming contact points between the single metal fibers by:

A. heating the plurality of fibers at a heating rate higher than 50 K/min, in particular higher than 100 K/min, especially higher than 200 K/min, preferably higher than 1000 K/min, to a fixation temperature selected in the range of 50 to 98% of their melting point temperature; and

B. keeping said fixation temperature for a fixation time selected in the range of 30 seconds to 30 minutes; and

C. cooling the plurality of fibers at a cooling rate higher than 20 K/min, preferably higher than 50 K/min, preferably higher than 100 K/min, in particular to a temperature below 60% of their melting point.

As described above, fibers which are subjected to heat tend to rearrange at an atomic level such that the largest possible volume with the smallest possible surface is achieved. The “most perfect” state, as seen from the fiber’s point of view, is a perfect sphere. Thus, with common fabrication processes the fibers start to rearrange at their atomic level, because of the heating step, to reach a more preferable energy level by, for example, crystallizing or by reducing defects in the crystal lattice of the fiber. In consequence, the fibers may even change their shape by

transforming their cross section form a flat or elliptic cross section into a circular cross section, i.e. rounding of the fibers' cross sectional shape occurs. During the transition towards the thermodynamically most preferred spherical shape not only rounding effects of the fibers' cross sectional shape can be observed, also changes in the diameters of the fibers can be observed. Before reaching the spherical shape, the fibers show sections with reduced diameters, herein referred to as constrictions. These constrictions develop further until the fibers are interrupted. Ultimately, the fibers transform into a plurality of droplets, i.e. they reach a spherical form.

The method of the present invention utilizes the kinetics of said rearrangement process. The rearrangement only takes place, when the fibers have sufficient time to do so. By increasing the heating rate as well as the cooling rate and by keeping the fixation temperature equal to or less than 30 minutes it can be ensured that the metal fibers create contact points where they connect with one another. Nevertheless, said rearrangement processes are reduced drastically and especially the shape changing effect, i.e. the rounding and the formation of constrictions and interruptions, can be avoided. Therefore, in the method of the present invention the heating rates as well as the cooling rates are kept well above 20 K/min, preferably higher than 50 K/min, preferably higher than 100 K/min. In this connection it is noted that it may be preferable to cool assembled network at said cooling rate to a temperature which is lower than 60% of the melting temperature of the fibers. Once the fibers are cooled down to said temperature rate, the cooling rate is not as crucial anymore and may thus also be lowered if necessary. Commonly known sintering processes take place at heating/cooling rates of about 10 to 20 K/min, thereby taking much longer to heat/cool the fibers (up to hours). When the heating rate is too low, relaxation processes may occur in the loose network of metal fibers before reaching the fixation temperature, reducing the surface component ΔG_S and the grain boundary component ΔG_B of the free energy. In consequence, when a low heating rate is applied in step A, the fixation time of 30 minutes or less in

step B might be insufficient for fixing the fibers to one another, since the fixation cannot benefit to the same extend from surface component ΔG_S and grain boundary component ΔG_B as when applying the higher heating rates in step A. Requiring more time for reaching the fixation temperature and/or keeping the fibers at a longer time at the fixation temperature results in the fibers being transformed into a thermodynamically more favored state, i.e. the cross section of the fibers may change towards round. As already mentioned above, when fibers attempt to transform into a thermodynamically more stable state, not only the cross section may change, also the width of the fibers may become non-uniform and/or constrictions of the fiber width occur. These constrictions may even interrupt the fibers, so that the fiber length is reduced, as demonstrated by the enclosed Figures and discussed in more detail below.

By applying the method of the present invention, the loose network of fibers can be assembled to a network of fixed fibers with minimal (unwanted) effects on their atomic level. In consequence, the fibers' cross sectional shape and length can be maintained. As explained above, with conventionally known methods this was not possible since said stored energy would be released from the fibers already during heating before reaching fixation temperatures. In consequence, for common sintering process the fibers are in a thermodynamically more stable state when reaching the fixation temperatures. In turn, higher fixation temperatures and higher fixation times are required, driving a change of the fibers' cross sections, diameters and/or lengths.

In the method according to the present invention, the temperature applied, i.e. the fixation temperature, depends on the material of the metal fibers. To avoid amorphous metal fibers from crystallizing during the welding process, it is preferable to keep the temperature applied below the crystallization temperature of these fibers. The crystallization temperature can, for example, be determined by differential scanning calorimetry (DSC) measurement for the metal fibers in question. DSC

measurement can be performed using the following conditions: Starting temperature 30 °C with a heating rate of 10 K min-1 until 1200 °C, continued with a cooling rate of 10 K min-1 until room temperature. DSC measurements may be performed in an argon atmosphere with a constant argon flow of 100 ml min-1 and a zirconium-oxygen-trap system for a complete oxygen free atmosphere (STA 449 F3 Jupiter, Netzsch Bj. 2017).

In the context of the description of the invention "% of the melting temperature" refers to the melting temperature in °C, as determined by, for example, differential scanning calorimetry (DSC) measurements. Accordingly, if the melting temperature is 1000 °C, in the context of the description of the invention 20% of the melting temperature is 200 °C, 50% of the melting temperature is 500 °C and 95% of the melting temperature is 950 °C.

Furthermore, as an additional effect, with the method according to the invention a network can be assembled which is flexible and can be deformed repeatedly without causing degradation of the network, i.e. without separating single metal fibers out of the network of metal fibers due to deformation. The metal fibers are fixed to one another, so that the metal fibers contact each other, i.e. the point of contact is not movable relative to the metal fibers as it is the case for example in a nonwoven agglomeration of entangled metal fibers, such as a metal felt. As a consequence, the network of metal fibers according to the invention is mechanically stable yet flexible. Mechanically stable in this context means that the network of metal fibers is not a loose agglomeration of metal fibers, i.e. the network does not disintegrate into isolated metal fibers as soon as a small force acts on the network. Accordingly, such a network of metal fibers can be flexibly deformed without breaking. It is possible that the network of metal fibers recovers its form after deformation. However, if the network of metal fibers is folded, it is also possible to reshape it permanently.

With the method according to the invention it is further possible that the contact points are distributed throughout the whole assembled network, so that throughout the 3-dimensional structure of the network of metal fibers contact points are present. Accordingly, the contact points are not only provided in a certain area of the network of metal fibers such as in the center or in the circumference of the network. It could be possible that the points of contact are evenly distributed throughout the network. It could further be possible that the density of contact points has a gradient throughout the network, i.e. that the network has areas with a higher density of contact points and areas with a lower density of contact. It is also possible to have ordered or random spatial distributions of contact points.

In this connection it is further noted that each of the metal fibers can have at least two contact points with other metal fibers, more preferably at least three contact points, even more preferably at least four contact points.

According to an embodiment before fixing the plurality of metal fibers to one another the method further comprises a step of subjecting the plurality of metal fibers to a predetermined pressure, which is in particular less than 1 MPa, especially less than 500 kPa. With the method according to the invention a comparatively low pressure can be applied in order to ensure the fibers create contact points where they connect to one another. With previously known methods, it was necessary to apply a rather high pressure in order to create contact points.

It is further preferable to provide a protective gas at said assembling site, such as argon, nitrogen, Ar-W5 (5 vol.-% H2 in Ar), Ar-W2 (2 vol.-% H2 in Ar), a forming gas (5 vol.-% H2 in N2) or other noble gases in order to avoid oxidation of the fibers during the assembling process. Generally, the method according to the invention can also be carried out in vacuum. Thus, the precise conditions at the assembling site may be chosen, for example, depending on the materials used for the fibers. For instance, some materials such as iron and/or some steels cannot be

used together with nitrogen since they tend to nitriding. Therefore, for such materials another protective gas may be used.

According to another embodiment of the invention the step of heating the fibers is carried out by a suitable heating device. Preferred examples for such heating devices are induction furnaces, infrared furnaces, high temperature ceramic heating elements and/or zone furnaces such as, for example, conveyor furnaces. Such heating devices can ensure a fast heating, i.e. high heating rates, as well as fast cooling, i.e. high cooling rates, such that the plurality of fibers can be connected to one another without having the fibers loose too much energy due to rearrangement and relaxation processes or anything alike before reaching the fixation temperature. The heating device may suitably be a continuous furnace or a batch furnace.

It is preferred that the fixation temperature is determined in-situ by electron microscopy. This can be done, for example, by placing fibers in an in-situ SEM (scanning electron microscope) heating stage. The fibers need a good thermal connection to the heating stage due to the nearly non-existing heat transfer in a high vacuum. For this, heat stabile graphite papers can be used. Hence, one sheet may be used as support between the fibers and the heating stage and another one with a hole in the middle may be used to view the fibers. These fiber sandwiches may then be transferred to the heating stage and pressed down. Afterwards, the heating stage may be heated to a temperature which is close, but still lower than the melting temperature of the fibers. Meanwhile, the fiber cross-section may be observed with the SEM until the fibers start to connect to one another. In this connection the fixation temperature may be determined. In a second experiment, the fiber sandwich may be heated at a heating rate, as mentioned above, to said determined fixation temperature. Said fixation temperature may then be held for a fixation time until the wanted degree of connection and therefore the wanted strength of connection is reached. Thus, in other words, in a second experiment the method steps A to C

according to the invention may be carried out in order to check whether the determined fixation temperature is correct.

Fixation temperature and time depends on the material of the fibers, the dimension of the fibers, i.e. width and thickness, and the amount of stored energy in the fibers. For example, for fine fibers of a given material having a low thickness and width rounding processes tend to occur faster compared to less fine fibers of the same material. Determining the fixation temperatures and times for a specific type of fiber is possible using either above mentioned in-situ by electron microscopy or by using trial and error tests. Trial and error tests can be carried out using the actual equipment for producing the network of metal fibers, i.e. under the actual manufacturing conditions.

In this connection it is noted that it may be preferred that the fixation temperature, i.e. the temperature maintained in step B, is selected in the range of 80 to 98%, in particular in the range of 90 to 98%, of the melting temperature of the metal fibers. Fixation temperatures in said range turned out suitable for most materials. In this connection it is noted that the precise fixation temperature may also depend on the fixation time. That is, the higher the fixation temperature, the shorter the fixation time may be and vice versa.

The cooling rate in step C is preferably maintained for a sufficient period for the metal fibers to cool below 60% of the melting temperature of the metal fibers.

Steps A, B and C are carried out in a combined period of time which is preferably less than 30 minutes, preferably less than 15 minutes, in particular less than 5 minutes, especially less than 1 minute. It has shown that the faster the method is performed the less negative side effects occur, such as for example release of energy, formation of fiber constrictions and/or interruptions and change of fiber cross-sectional shape. Also in this context, it is to be noted that the cooling of step C

does not necessarily require a cooling until room temperature. Step C may be terminated after cooling to a temperature of 60% of the melting temperature of the metal fibers.

In this connection it is noted that it may be possible that the predetermined period of time is equally split up between said steps A, B and C. In other embodiments it can also be possible that the step B takes much longer compared to steps A and C. In an ideal experiment, for example, steps A and C may take 1 minute while step B may take 30 seconds. In other experiments, however, step A may be carried out within 1 to 5 minutes, step B within 0.5 to 1 minute and step C within 10 minutes until the assembled network is cooled down to a temperature of about 60% of the melting temperature of the used fibers. The further cooling of the assembled network to room temperature may, for example, take another 1 to 2 hours.

It may be preferable that the metal fibers comprise a length of 1.0 mm or more and/or a width of 100 µm or less and/or a thickness of 50 µm or less. With the metal fibers having such dimensions, it is possible to produce the network with metal fibers that are fixed to one another, without needing to heat the metal fibers for a time of more than 30 minutes to temperatures close to their melting point. Conventional sintering techniques require temperatures close or even slightly above the melting temperature of the metal to be maintained for a relatively long period of time. This can result in melting or at least softening the material of the metal fibers to a certain degree, so that the metal fibers form a metal foil rather than a network, in particular when relatively high pressure is applied during sintering. Since the network of metal fibers is not a metal foil, i.e. the structure of the metal fibers used for producing the network of metal fibers can still be recognized in the network of metal fibers. Accordingly, in a cross-sectional view of network of metal fibers, there are voids which are not part of the metal fibers but are in between the metal fibers of the network fibers.

In accordance with the present invention, it is preferable that the metal fibers, before fixing them one to another, show an exothermic event when heated in a DSC measurement, wherein the exothermic event releases energy in an amount of 0.1 kJ/g or more, more preferably in an amount of 0.5 kJ/g or more, even more preferably in an amount of 1.0 kJ/g or more and most preferably in an amount of 1.5 kJ/g or more. The absolute amounts depend very much on the used metal or metal alloy. The extent of the exothermic event can be determined by comparing DSC measurements of the metal fibers before and after thermal equilibration. In other words, the metal fibers showing such an exothermic event are not in their thermodynamic equilibrium at ambient temperatures. During heating in a DSC measurement, the metal fibers can transit from a metastable to a thermodynamically more stable condition, e.g. by crystallization, recrystallization or other relaxation processes reducing defects in the lattice of metal atoms. An exothermic event observed for the metal fibers when being heated, e.g. during a DSC measurement, indicates that the metal fibers are not in their thermodynamic equilibrium, e.g. the metal fibers can be in an amorphous or nanocrystalline state containing defective energy and/or crystallization energy which is released during heating of the metal fibers due to occurrence of crystallization or recrystallization. Such events can be recognized e.g. using a DSC measurement. It was found that networks of metal fibers which show such an exothermic event have an improved strength after the metal fibers are fixed to one another.

According to another embodiment the metal fibers comprise a non-round cross section, in particular a rectangular, quadratic, partial circular or an elliptical cross section with a large axis and a small axis. Such cross-sections usually lead to fibers which are not in their thermal equilibrium, i. e. in a metastable state, which, for some applications, may be beneficial.

In this connection it is noted that, obviously, the value of the small axis must be smaller than the value of the large axis. In the case in which the small axis comprises a higher value, i.e. a greater length, than the large axis, the definition of "small" and "large" must simply be interchanged.

It may be preferred that a ratio of the small axis to the large axis lies in the range of 1 to 0.05, preferably in the range of 0.7 to 0.1, in particular in the range of 0.5 to 0.1. As it is generally known, the ratio between the lengths of the small and the large axis of an ellipse is higher the more the ellipse looks like a circle, for which the ratio would be 1. The smaller the value of the ratio is, the flatter is the ellipse. Thus, the ratio of the small axis to the large axis is in particular less than 1.

Alternatively, the metal fibers may comprise a round cross-section. For such a cross-section a ratio of a “large” axis to a “small” axis would obviously be exactly 1. Round cross-sections comprise an energetically more preferred state the cross-sections comprising an aspect ratio that is smaller than 1. Hence, fibers with round cross-sections are energetically closer to their equilibrium state than fibers with cross-sections of other shapes.

According to another embodiment of the invention the metal fibers are obtainable by subjecting a molten material of the metal fibers to a cooling rate of 10^2 K min^{-1} or higher, in particular by vertical or horizontal melt spinning. Such metal fibers produced by melt spinning can contain spatially confined domains in a high-energy state (i. e. in a metastable state), due to the fast cooling applied during the melt spinning process. Fast cooling in this regard refers to a cooling rate of 10^2 K·min^{-1} or higher, preferably of 10^4 K·min^{-1} or higher, more preferably to a cooling rate of 10^5 K·min^{-1} or higher.

Also, fibers obtained by melt spinning often comprise a rectangular or semi-elliptical cross section, which are preferred for certain application fields since they are

far away from their equilibrium state. Examples for melt spinners with which such fibers can be produced are for example known from the not yet published international application PCT/EP2020/063026 and from published applications WO2016/020493 A1 and WO2017/042155 A1, which are hereby incorporated by reference.

According to another example, at least some of the metal fibers of the plurality of metal fibers are amorphous or at least some of the metal fibers of the plurality of metal fibers are nanocrystalline. Nanocrystalline metal fibers contain crystalline domains. Upon heating to a temperature of about 20-60% of the melting temperature of the nanocrystalline metal fibers, these domains undergo recrystallization resulting in an increase of the average size of crystalline domains compared to the average size of the initial crystalline domains in the nanocrystalline metal fibers before heating. It is also possible to mix non-equilibrated (e.g. nanocrystalline or amorphous fibers) with equilibrated (e.g. annealed) fibers.

In some applications it is preferred that the metal fibers are in electrical contact with one another. This can for example be preferable if the assembled networks are supposed to be used in electrochemical applications, such as batteries, fuel cells or anything alike.

According to an embodiment the metal fibers are in direct electrical contact with one another such that the electrical conductivity can be enhanced to a maximum. In this regard it is particularly preferable that all of the metal fibers are sintered to other metal fibers, most preferable directly to other metal fibers, without the need of an additional binder, e.g. a polymeric binder. It is therefore further preferred that the metal fibers are fixed to one another without a polymeric binder, since such polymeric binders often have a poor electrical conductivity and high temperature performance.

It may be preferable that the metal fibers contain at least one of copper, silver, gold, nickel, palladium, platinum, cobalt, iron, chromium, vanadium, titanium, aluminum, silicon, lithium, manganese, boron, combinations of the foregoing and alloys containing one or more of the foregoing, such as CuSn8, CuSi4, AlSi1, Ni, stainless steel, Cu, Al or vitrovac alloys. Vitrovac alloys are Fe-based and Co-based amorphous alloys. It may particularly be preferred if the metal fibers are made of copper or of aluminum or of a stainless steel alloy. Different types of metal fibers can be combined with each other, so that the filter can contain for example metal fibers made of copper, one or more stainless steel alloys and/or aluminum. Networks being made out of metal fibers, wherein the metal fibers are of copper, aluminum, cobalt, stainless steel alloys containing copper, aluminum, silicon and/or cobalt, are particularly preferred.

According to another aspect of the invention a network of metal fibers is provided, wherein said network comprises a plurality of metal fibers fixed one to another at contact points, and wherein the metal fibers either comprise a non-round cross section, for example a rectangular, quadratic, partial circular or an elliptical cross section with a large axis and a small axis, or wherein the metal fibers comprise a round cross section. The fibers further comprise a width which is generally constant along a length of the fiber such that a variation of the width of the fiber along its length is preferably less than 40%, more preferably less than 30% or even more preferably less than 20%.

Preferably, the width of the fibers along their length changes by less than 20%, more preferably by less than 10%, even more preferably by less than 5% or most preferably by less than 1%. The change of the fibers' widths refers herein to a comparison of a fiber width before and after sintering the fibers to one another.

In conventionally known networks, the fibers usually comprise random shapes such that it cannot be ensured that the width of a single fiber does not vary very

much along its length. If a fiber, for example, would comprise large variations of its width, it could be possible that said fiber would tear apart at a section which comprises a smaller width, i.e. the fiber has a constriction which turns then into an interruption. Fibers with a (nearly) constant width, on the other hand, have to advantage that the single fibers can connect to one another at any given point along their length without showing the risk of being interrupted during this process.

In this connection it is noted that it is preferable that the metal fibers are substantially constant in width, i.e. the width variation of the fiber along its length is preferably less than 40%, more preferably less than 30% or even more preferably less than 20%. As mentioned above, when metal fibers are heated up at a low heating rate, rearrangement processes on an atomic level occur in order to reach an energetic level which is closer to their equilibrium state. This sometimes even leads to changes in the shapes of the fibers since a perfect sphere would be the most preferred state. When such shape changes start to arise it can be possible that the fibers begin to decompose by building up constrictions which can cause interruptions of said fibers. Ultimately, the fibers transform into metal droplets when heated too long. The method according to the invention utilizes fast heating and cooling rate and a reduced fixation time. In the resulting network of fixed metal fibers, the fibers are substantially free of such interruptions such that the length of the fibers is preserved. Further, due to the high heating and cooling rates and the reduced fixation time, shape changes of the fibers cross section can be avoided, i.e. there is a kinetic control over the fiber shape. In consequence, the method of the present invention provides high control about the fiber shape.

It can be preferred that the plurality of fibers is sintered one to another, more preferred directly sintered to one another. This ensures that no further frame or anything alike is needed in order to keep the fibers together. Furthermore, by directly sintering the metal fibers to one another, the points of connection are electrically

conductive. This provides a relatively low internal resistance for the network of metal fibers.

It may be preferable that a ratio of the small axis to the large axis lies in the range of 1 to 0.05, preferably in the range of 0.7 to 0.1, in particular in the range of 0.5 to 0.1. As already mentioned above fibers with a flatter cross-section are energetically wise further away from their equilibrium state such that they store more energy compared to fibers which comprise, for example, a round cross-section.

It may in fact be possible to choose the characteristics network according to the application of the network by using fibers with a higher or lower ratio between the lengths of the small and large axis as described above. Hence, by using fibers with a lower ratio, the mechanical stability as well as the weight of the network decreases, whereas by using fibers with a higher ratio, the mechanical stability as well as the weight of the network increases. It may be chosen according to the application which characteristic is more important. Due to the kinetic control provided by the present invention, the fibers' shapes are substantially maintained, i.e. the fibers' aspect ratios are substantially preserved. In consequence, the network characteristics can be easily adjusted by starting with fibers having the desired final shape.

According to an embodiment the network is an ordered or an unordered network. Such an unordered network has, for example, a good electrical conductivity in every direction and anisotropic fluidic properties. Moreover, it is easier to produce an unordered network of metal fibers, compared to an order network of fibers. Nevertheless, in some applications it may be preferred that the fibers in the network are combed in different directions to provide directionality of individual fibers. Accordingly, it may be preferred that in the network some or all of the fibers have an orientation, i.e. the lengths of the fibers are not oriented randomly but have a

predominant orientation in one or more spatial direction. By having a predominant orientation of the metal fibers, the filter can have isotropic fluidic properties.

According to another embodiment of the invention the network has open pores between the metal fibers of the plurality of metal fibers. The porosity of the network is preferably up to 95 vol%. It is also preferable that the porosity of the network is more than 80 vol%. It is even more preferable when the porosity is in the range of 80 vol% to 95 vol%. It is possible to incorporate active materials into the open pores, such as active electrode materials or active catalyst materials. It is further preferable that in the network according to the invention at least some of the metal fibers of the plurality of metal fibers are at least partially coated. The coating can for example be an active material, such as an electrode active material which interacts with Li-ions in batteries or a catalytically active material which coverts CO to CO2 or is active in hydrolysis. It is also possible to apply a coating onto the metal fibers which improves the fixation of the metal fibers to one another, and thereby increases the mechanical strength of the network. The porosity can be determined using a micro-computertomograph to reproduce the network structure and then evaluate the porosity using the bubble point method described below.

By way of example, such active electrode materials for batteries are: for the anode: Graphite, Silicon, Silicon-Carbide (SiC) and Tin-Oxide (SnO), Tin-Dioxide (SnO2) and Lithium-Titanoxide (LTO); and for the cathode: Lithium-Nickel-Manganese-Cobalt-Oxide (NMC), Lithium-Nickel-Cobalt-Aluminium-Oxide (NCA), Lithium-Cobalt-Oxide (LiCoO2) and Lithium-Iron-Phosphate (LFP).

The network may comprise an average mean pore size selected in the range of 0.1 to 100 μm, preferably in the range of 0.5 to 50 μm, in particular in the range of 1 to 10 μm. The mean pore size can be determined using a micro-computertomograph to reproduce the fiber structure and then evaluate the mean pore diameter using the bubble point method. The bubble point method determines the largest

ball diameter, which might fit between two fibers, which is considered the pore size. More in detail, a point is placed at the center between two fibers and the radius of the bubble, with the point as a center is increased, until contact to the surface of both fibers is made. The diameter of the bubble corresponds to the pore size. If at any given parameter the bubble diameter only contacts one fiber, the center point is displaced into the direction of the fiber that the bubble did not contact.

It is particularly preferable if the network of metal fibers according to the invention the metal fibers are fixed, in particular directly fixed, to one another at points of contact which are randomly distributed throughout the network of metal fibers. According to another inventive aspect, it is preferred that the points of contact are not randomly distributed but are provided e.g. in a peripheral region of the network of metal fibers or that the metal fibers are ordered so that also the point of contacts are ordered. It is further preferred that the points of contact at which the metal fibers are fixed to one another are localized in specific areas and not provided evenly over the complete network of metal fibers. With the points of contact at which the metal fibers are fixed to one another being present only in separated areas, it is possible that the fibers inbetween these areas have a high flexibility whilte at the same time the mechanical stability and good electrical conductivity is ensured.

The thickness of the network of the invention is not particularly limited. However, it can be preferred if the network has a thickness of 0.01 mm or more. It is more preferred that the thickness of the network is 0.03 mm or more, even more preferred 0.05 mm or more, even more preferred 0.07 mm or more and most preferred 0.1 mm or more. If the thickness of the network is less than 0.01 mm, there is a risk that the mechanical stability of the network is not sufficient. The upper limit for the thickness of the network is not particularly limited. However, depending on the ap-

plication, the upper limit may be 3.0 mm or less, or 2.5 mm or less. For battery applications, a preferred thickness of the network is in the range from 0.1 mm to 0.5 mm. A network with a thickness in this range is advantageous concerning the stacking and rolling of the active material coated network for producing batteries. Another preferred thickness range is in the range of greater than 0.5 mm to 5 mm, more preferably in the range of 1 to 3 mm.

According to another aspect of the invention a network of metal fibers is provided, wherein said network may for example be the network according to the invention, that is obtainable by the method according the invention.

The invention will now be described in further detail and by way of example only with reference to the accompanying drawings and pictures as well as by various examples of the network and method of the invention. In the drawings there are shown:

Fig. 1: an exemplary scheme illustrating typical processes that may occur during sintering;

Fig. 2: frames of a video showing sintering and relaxation of CuSi4;

Fig. 3: frames of a video showing sintering and relaxation of AlSi1;

Fig. 4: micrographs of a conventionally sintered fiber network;

Fig. 5: micrographs of sintered CuSi4 fibers having a flat shape; and

Fig. 6: micrographs of sintered AlSi1 fibers having a flat shape.

Figure 1 shows the typical diffusion processes causing relaxation during a sintering process. The different arrows show the surface diffusion 1, the lattice diffusion (from the surface) 2, the evaporation and condensation 3, the grain boundary diffusion 4, the lattice diffusion (from the boundary region) 5 and the volume diffusion 6. While processes 1-3 lead to no shrinkage and only connect the fibers to one another, processes 4-6 remove material from the border region and deposit it on the sintered necks. The reason for this, as it is already explained above, is the reduction of the surface of the fibers and the associated reduction in their free energy ΔG.

By the method of the present invention only the border region of the metal fibers is thermally activated so that the fibers 10 sinter together but not the whole fiber 10 is rounded in order to maintain the fiber shape and dimension, which may be associated with an enlarged surface providing beneficial properties for many applications, e.g. electrochemical applications or filtering applications.

The method, according to the invention, a loose network of fibers 10 is provided at the assembling site 12. Said fibers 10 are then fixed to one another by forming points of contact 14 between the single fibers 10. For creating said contact points 14, the method according to the invention provides three steps:

A. The plurality of fibers 10 is heated at a heating rate higher than 50 K/min, in particular higher than 100 K/min, especially higher than 200 K/min, preferably higher than 1000 K/min, to a fixation temperature selected in the range of 50 to 98% of their melting point temperature.
B. Then said fixation temperature is kept for a fixation time selected in the range of 30 seconds to 30 minutes.
C. At last, said plurality of fibers 10 is cooled at a cooling rate higher than 50 K/min, preferably higher than 100 K/min, in particular to a temperature below 60% of their melting point

Additionally, before performing said three steps A, B and C, the fibers 10 can be subjected to a pressure to ensure that the single fiber 10 come into contact with each other. Said pressure can be relatively low, i.e. in the range of 0.05 to 1 GPa and serves the formation of contacts between the unconnected metal fibers. It is not necessary to maintain the pressure when carrying out steps A, B and C, i.e. it is sufficient to compress the fibers briefly by applying said pressure only before but not during carrying out steps A, B and C. It is preferred to not apply an external pressure force during steps A, B and C. By avoiding external pressure force, the risk of transforming the metal fibers into a metal foil can be avoided, in particular when operating with fixation temperatures close to the melting temperature.

As can be seen, compared to conventionally known methods, steps A, B and C are performed more quickly. A maximum time for performing all three steps can be defined as less than 45 minutes, even in the range of about 15 minutes. It could already be shown that times below 5 minutes and even below 1 minute are possible with the method according to the invention. This lies well below the common times used for sintering which conventionally takes up to several hours.

In order to be able to realize such short time frames, steps A, B and C are performed with a furnace or another heating device which is configured to provide high heating and cooling rates such as an induction furnace, infrared furnace, high temperature ceramic heating elements and/or zone furnaces such as, for example, conveyor furnaces (not shown in the drawings).

It is of particular interest that the fibers 10 which are supposed to be connected to one another, are heated up to a precise fixation temperature which lie in the range of 50 to 98%, in particular in the range of 80 to 98%, more particular in the range of 90 to 98%, of the melting temperature of said fibers 10. The precise fixation temperature depends on the materials used for the fibers 10 (see also Tables 1

and 2 below). Choosing the right fixation temperature allows to connect the fibers 10 to one another without having them start to change their shape, i. .e. to round, because of the above described relaxation processes, or without having them start to melt.

In order to being able to determine said fixation temperature and time, trial and error experiments and/or electron microscopic examinations can be carried out on samples of the actual metal fibers. For the electron microscopic examination, fibers are placed in an in-situ SEM (scanning electron microscope) heating stage. For this, the fibers need a good thermal connection to the heating stage due to the nearly non-existing heat transfer in a high vacuum. Therefore, heat stable graphite papers can be used: for example one sheet as support between the fibers and the heating stage and another one with a hole in the middle to view the fibers. Such fiber sandwiches are then transferred in the heating stage and pressed down. Afterwards, the heating stage is heated to a temperature close to the melting temperature. The fiber cross-section is then observed with the SEM until the fibers start to connect with one another. This way, the fixation temperature is determined. In a second experiment, the above mentioned steps A to C are carried out until the wanted degree of connection and therefore the wanted strength of connection is reached. For such trial and error experiments, an amount of fibers is placed in a fast heating furnace. To achieve contact points between the fibers, the network can be pressed together or placed on a plate with a space holder and a cover plate. After removing the air/oxygen in the furnace and setting the test atmosphere, the furnace is heated to the possible, i. e. the determined, fixation temperature and held for a certain time, which might be the fixation time. Depending on the result of the fibers, e.g. depending on whether the fibers connected to one another and/or whether the fibers changed their shape, the parameters must be adjusted. In this connection it is noted that three possible outcomes can be expected: 1) the fibers are not sintered, 2) the fibers are sintered but round or 3) the fibers are not sintered but round. For the first outcome, the fixation temperature

and/or fixation time should be increased. For the second outcome the fixation temperature and/or the fixation time should be decreased and for the third outcome the heating rate should be increased and the fixation temperature and/or the fixation time decreased.

For some materials it is also beneficial if a protective gas, such as for example argon, nitrogen Ar-W5 (5 vol.-% H2 in Ar), Ar-W2 (2 vol.-% H2 in Ar), a forming gas (5 vol.-% H2 in N2) or other noble gases, is provided at the assembling site 12 in order to prevent the metal fibers 10 from oxidizing. It can be chosen according to the material(s) of the fibers 10 if it is necessary to provide such a protective gas or not.

The contact points 14 of the assembled network can be distributed in an ordered or unordered manner throughout the network depending on the application of the assembled network and fix the fibers to one another. Also, the amount of contact points 14 can be chosen according the application of the network by subjecting the fibers 10 to a higher or lower pressure before carrying out steps A to C such that more or less contact points 14 are created. Also the fiber density, i.e. the amount of fibers per volume, and/or the fineness of the fibers can be used to tune the number of contact points 14.

Said contact points 14 also enable an electric conductivity throughout the assembled network. Therefore, a high amount of contact points 14 can be beneficial for applications where a high electrical conductivity of the network is needed. For filters, on the other hand, it may not be that crucial how many contact points 14 are provided throughout the network as long as it still holds all the fibers 10 together.

The fibers 10, which are used for assembling a network according to the invention comprise a length of 1.0 mm or more and/or a width of 100 µm or less and/or a thickness of 50 µm or less (see Figs. 2 to 6). Such fibers 10 can, for example, be

produced by so called vertical or horizontal melt spinning processes, which are described in documents PCT/EP2020/063026 (not yet published), WO2016/020493 A1 and WO2017/042155 A1. These fibers 10 often comprise a cross-section is shaped oval, rectangular or flat in general. Furthermore, fibers 10 which are produced by melt spinning often store a high amount of energy.

In order to understand the method according to the invention in a better way, several experiments have been conducted which are described below in connection Figs. 2 to 6.

Fibers of the copper alloy (CuSi4 (4 wt .-% Si and 96 wt .-% Cu) and AlSi1 (1% by weight Si and 99% by weight Al)) have been sintered together while maintaining the flat, ribbon like, structure of the fibers. In order to systematically examine the processes, the fibers were heated in an electron microscope with a heating rate of 10 K/min and a video was recorded. Figure 2 shows single frames from the CuSi4 videos at special points such as the start of the sintering (to see that the sharp transitions 14 between the fibers 10 are blurred, left) and the point at which the fibers 10 start to round off so much (right) that constrictions 15 and interruptions 16 are formed, decomposing the fibers 10. The corresponding temperatures are very close to each other, which is why the highest temperature accuracy and control is necessary to achieve good results.

Figure 3 shows frames from a video taken with AlSi1 fibers under the same conditions as the video of Fig. 2. Fig. 3 shows the same characteristic points as explained for Figure 2, i.e. the onset of sintering and the begin of rounding processes. It could be observed that the fibers sinter together at around 602 °C, whereas at 624 °C. Further, between 602 °C and 624 °C the fibers transformed from flat ribbon like fibers towards fibers having a round cross section. This can be recognized by the fibers at 624 °C being thinner than at 602 °C. It is noted that the videos of which frames are shown in Fig. 2 and 3 were recorded under low heating

conditions (10 K/min) in a high vacuum condition. These conditions are different from those of the present invention. This is the reason why the values indicated in Fig. 2 and 3 are different from the values described in the tables below. Nevertheless, Fig. 2 and 3 demonstrate the difficulties of sintering the fibers under conventional methods applying lower heating rates.

With classic thermal sintering using furnaces, such as resistance heated furnaces, the fibers 10 are heated with a rate of 10-20 K/min, i.e. relatively slowly. During this time, the fibers 10 undergo a so-called relaxation process and the energy stored in these fibers from their production, for example by the melt spinning process, is slowly released and no longer available for forming points of connection between the metal fibers. The release of the stored energy during slow heating does not only influence the mechanical properties of the fibers 10 but also increases the energy requirement during the actual sintering because the fibers 10 are no longer in their thermodynamic imbalance as they were after production. For this reason, the untreated fibers 10 as obtained from a melt spinning process and for comparison fibers 10 tempered at 300 °C for 1 hour were brought to the sintering temperature in a fast heating furnace (here an infrared furnace) within 1 minute. This temperature was held for 1 minute and then cooled as quickly as possible (from sintering temperature to less than 600 °C in less than 30 seconds). In addition to infrared heaters, other possible heating devices are e.g. ceramic heaters or induction heaters. The very short process time of only 1 minute or less is sufficient for the fibers 10 to sinter with one another at the contact points 14, but the energy and time are not sufficient for the fibers 10 to make a transition into the thermodynamically favoured round shape. This is not possible when applying conventional heating and cooling rates, requiring a lot of time for reaching the target temperature (from sintering temperature to less than 600 °C in some hours). Applying conventional heating and cooling rates still makes it possible to sinter the fibers 10 to one another. However, the sintered fibers have then adapted the idealized round shape and were damaged by constriction 15 or even interruptions 16

which may occur e.g. at twisting points. Due to the very long diffusion paths when the fibers become round, either high temperatures and/or long times are necessary for the transformation into the thermodynamically favoured round shape. This can be avoided by using fibers containing the stored energy e.g. from production by melt spinning. The stored energy can be measured e.g. by DSC measurement, where it can be observed in the form of an exothermic event.

It has further been tested, for how long fibers 10 made out of AlSi1 and CuSi4, respectively, have to be heated at certain temperatures until they reach their idealized round shape. Fibers of AlSi1 had a ribbon like structure with an average length of 30 mm, an average width of 75 µm and an average thickness of 15 µm. Fibers of CuSi4 had a ribbon like structure with an average length of 20 mm, an average width of 35 µm and an average thickness of 7 µm. For these tests, the fibers were heated within 1 min to the determined fixation temperature indicated in the table below. Said fixation temperatures were maintained for some time, before rapidly natural cooling within 30 sec to around 500 °C and around 20 min to room temperature for CuSi4 and within 30 sec to around 330 °C and 15 min to room temperature for AlSi1. After cooling the fibers were examined about whether they have a rounded cross section. Experiments were repeated with increasing fixation times at the respective fixation temperatures. The results of these tests are indicate in the following table:

Fiber Material	Fixation Temperature in °C	Time in minutes until fibers have a round cross section
AlSi1	630	30
AlSi1	660	5
CuSi4	850	30
CuSi4	900	15
CuSi4	950	5

One can clearly see that the higher the fixation temperature is chosen, the shorter time one has left in order to sinter the fibers 10 to one another without having them transform their outer shape. Furthermore, it can be seen that the temperature clearly depends on the material out of which the fibers 10 are made. Further the fiber size, in particular thickness and width have a certain influence on the velocity with which the cross sectional shape of the fiber transforms from flat to round. The above experiments demonstrated how the skilled person can easily determine the suitable conditions by simple trial and error for each fiber material.

Even though metal fibers differing in regard to their material and/or dimensions may require different conditions for fixing them to one another, above empirical studies proof that if the time frame during which the fibers 10 are sintered to one another is reduced to a minimum, said fibers 10 can be connected to a network without having the fibers 10 changing their length, shape and/or diameter.

Figure 4 shows a conventionally sintered network of previously flat fibers 10. The formation of constrictions 15 and interruptions 16 of the fibers 10 can be clearly seen. Further, the cross section of the fibers was transformed from flat to round. The formation of sintering necks, i.e. constrictions, corresponds to the current theory as described in connection with Fig. 1.

Table 1 shows the sintering temperatures (holding time 1 min in each case) for the thermally untreated (as obtained from melt spinning) and for tempered (1 hour at 300 °C under argon atmosphere) CuSi4 fibers 10 with a ribbon like structure having an average length of 20 mm, an average width of 35 µm and an average thickness of 7 µm. Table 2 analogously shows the same for AlSi1 fibers 10 having an average length of 30 mm, an average width of 75 µm and an average thickness of 15 µm. Comparisons between untreated and tempered fibers were made, using a tube furnace under a protective gas atmosphere (argon) providing heating rates of

10 K/min. It was found that a temperature of at least 950 °C and a holding time of at least 1 hour are necessary for tempered CuSi4 fibers 10 in order to sinter the fibers 10 together. After sintering, the previously tempered fibers 10 are almost perfectly round and, in some cases, are severely restricted in length by constrictions 15 and interruptions 16. In contrast, sintering of thermally untreated CuSi4 fibers begins at significantly lower temperatures (between 890 and 910 °C) compared to the tempered fibers (begin of sintering above 950 °C) and is completed within 0.5 to 5 minutes for CuSi4 fibers and 0.5 to 5 minutes for AlSi1 fibers, depending on the fixation temperature with lower fixation temperatures requiring longer fixation times.

Table 1: CuSi4 sinter-parameters

Fixation temperature °C	thermally untreated fibers	tempered fibers
890	not sintered	not sintered
910	sintered	not sintered
930	sintered	not sintered
950	sintered	not sintered; start of rounding
970	sintered; start of rounding	sintered; rounded

Table 2: AlSi1 sinter-parameters.

temperature °C	thermally untreated fibers	tempered fibers
620	not sintered	not sintered
630	sintered	not sintered
640	sintered	sintered; start of rounding
660	sintered	sintered; rounded

Comparative experiments with relaxed fibers 10 (thermally treated for 1h at 300 °C under protective gas, no change in shape, only degradation of the defects and release of stored energies) show that the sintering described here is not possible or

only possible at higher temperatures in comparison to fibers 10 which were untreated. For the relaxed fibers, the temperature window between begin of sintering and change of fiber shape is very narrow. However, when using fibers having stored energy, e.g. fibers showing an exothermic signal during DSC measurement, the temperature window for sintering the fibers to one another without rounding, is much wider. With the slow heating and cooling rates of know sintering processes, the fibers 10 experience a relaxation process before sintering temperatures can be reached, releasing stored energy too early, so it is not available for driving the sintering process. When applying low heating rates, the fibers are tempered before reaching the sintering temperature. In consequence, they will behave similar to the tempered fibers reported in tables 1 and 2. The higher the energy stored in the fibers 10 during the manufacturing process, the lower the required sintering temperature and time can be.

The greatest possible energy can be introduced through high quenching rates, e.g. by the known melt spinning process. Due to the fundamental mechanisms of the process, the method according to the invention can be transferred to almost all metallic, metallic-inorganic and comparable alloys and materials, as long as sufficient energy is stored in them.

Fig. 5 shows CuSi4 fibers 10 which have been sintered with the method according to the invention such that they have still retained their original flat shape. Fig. 6 shows the same for AlSi1 fibers 10. It can clearly be seen that the fibers 10 in Figs. 5 and 6 comprise an almost constant width along their length, i.e. no constriction 15 or even interruptions 16 were formed which may lead to a complete destruction of the fibers 10. That is, the width of the fibers 10 in the network according to the invention does not vary more than 40%, preferably not even more than 30%.

Claims

1. Method of assembling a fiber network comprising a plurality of metal fibers (10), wherein the method comprises the following steps:
   - providing a loose network out of the plurality of metal fibers (10) at an assembling site (12);
   - fixing the plurality of metal fibers (10) to one another by forming contact points (14) between the single metal fibers (10) by:
     A. heating the plurality of fibers (10) at a heating rate higher than 50 K/min, in particular higher than 100 K/min, especially higher than 200 K/min, preferably higher than 1000 K/min, to a fixation temperature selected in the range of 50 to 98% of their melting point temperature; and
     B. keeping said fixation temperature for a fixation time selected in the range of 30 seconds to 30 minutes; and
     C. cooling the plurality of fibers (10) at a cooling rate higher than 50 K/min, preferably higher than 100 K/min.

2. The method of assembling a fiber network according to claim 1, wherein before fixing the plurality of metal fibers (10) to one another the method further comprises a step of subjecting the plurality of metal fibers (10) to a predetermined pressure, which is in particular less than 1 GPa.

3. The method of assembling a fiber network according to claim 1 or 2, wherein a protective gas is provided at said assembling site (12), such as argon, Ar-W5 (5 vol.-% H2 in Ar), Ar-W2 (2 vol.-% H2 in Ar), a forming gas (5 vol.-% H2 in N2) or other noble gases.

4. The method of assembling a fiber network according to one of the preceding claims,
wherein the step of heating the fibers (10) is carried out by an induction furnace, infrared furnace, high temperature ceramic heating elements and/or zone furnaces such as, for example, conveyor furnaces.

5. The method of assembling a fiber network according to one of the preceding claims,
wherein the fixation temperature is determined in-situ by electron microscopy.

6. The method of assembling a fiber network according to one of the preceding claims,
wherein the fixation temperature is selected in the range of 80 to 98%, in particular in the range of 90 to 98%, of the melting point temperature of the metal fibers.

7. The method of assembling a fiber network according to one of the preceding claims,
wherein steps A, B and C are carried out in a predetermined period of time which is less than 30 minutes, preferably less than 15 minutes, in particular less than 5 minutes, especially less than 1 minute.

8. The method of assembling a fiber network according to one of the preceding claims,
wherein the predetermined period of time is equally split up between said steps A, B and C.

9. The method of assembling a fiber network according to one of the preceding claims,

wherein in step C the cooling rate is maintained higher than 50 K/min, preferably higher than 100 K/min, until the fibers are cooled to a temperature of 60% or less of the melting point temperature of the metal fibers.

10. The method of assembling a fiber network according to one of the preceding claims,
wherein the metal fibers (10) comprise a length of 1.0 mm or more and/or a width of 100 µm or less and/or a thickness of 50 µm or less.

11. The method of assembling a fiber network according to one of the preceding claims,
wherein the width of the fibers along their length changes by less than 20%, more preferably by less than 10%, even more preferably by less than 5% or most preferably by less than 1%, compared to the initial width of the fibers before conducting step A.

12. The method of assembling a fiber network according to one of the preceding claims,
wherein the metal fibers (10) before and/or after fixing them one to another show an exothermic event when heated in a DSC measurement, wherein the exothermic event releases energy preferably in an amount of 0.1 kJ/g or more, more preferably in an amount of 0.5 kJ/g or more, even more preferably in an amount of 1.0 kJ/g or more and most preferably in an amount of 1.5 kJ/g or more.

13. The method of assembling a fiber network according to one of the preceding claims,
wherein the metal fibers (10) comprise a non-round cross section, in particular a rectangular, quadratic, partial circular or an elliptical cross section with a large axis and a small axis.

14. The method of assembling a fiber network according to claim 13, wherein a ratio of the small axis to the large axis lies in the range of 1 to 0.05, preferably in the range of 0.7 to 0.1, in particular in the range of 0.5 to 0.1.

15. The method of assembling a fiber network according to one of the preceding claims 1 to 10, wherein the metal fibers (10) comprise a round cross-section.

16. The method of assembling a fiber network according to one of the preceding claims, wherein the metal fibers (10) are obtainable by subjecting a molten material of the metal fibers to a cooling rate of 10^2 K min^{-1} or higher, in particular by vertical or horizontal melt spinning.

17. The method of assembling a fiber network according to one of the preceding claims, wherein at least some of the metal fibers (10) of the plurality of metal fibers are amorphous or wherein at least some of the metal fibers (10) of the plurality of metal fibers are nanocrystalline.

18. The method of assembling a fiber network according to one of the preceding claims, wherein the metal fibers (10) are in electrical contact with one another.

19. The method of assembling a fiber network according to one of the preceding claims, wherein the metal fibers (10) are in direct electrical contact with one another.

20. The method of assembling a fiber network according to one of the preceding claims,
wherein the metal fibers (10) contain at least one of copper, silver, gold, nickel, palladium, platinum, cobalt, iron, chromium, vanadium, titanium, aluminum, silicon, lithium, manganese, boron, combinations of the foregoing and alloys containing one or more of the foregoing, such as CuSn8, CuSi4, AlSi1, Ni, stainless steel, Cu, Al or vitrovac alloys.

21. Network of metal fibers,
comprising a plurality of metal fibers fixed one to another at contact points (14);
wherein the metal fibers (10) non-round cross section, in particular a rectangular, quadratic, partial circular or an elliptical cross section with a large axis and a small axis, or
wherein the metal fibers (10) comprise a round cross section, and
wherein the fibers (10) comprise a width which is generally constant along a length of the fiber such that a variation of the width of the fiber along its length is less than 40%, preferably less than 30%, in particular less than 20%.

22. The network according to claim 21,
wherein the metal fibers (10) of the plurality of metal fibers do not comprise constrictions (16).

23. The network of metal fibers according to claim 21 or 22,
wherein the single fibers of the plurality of fibers are sintered one to another.

24. The network of metal fibers according to one of the preceeding claims claim 21 or 23,
wherein a ratio of the small axis to the large axis lies in the range of 1 to 0.05, preferably in the range of 0.7 to 0.1, in particular in the range of 0.5 to 0.1.

25. The network of metal fibers according to one of the preceding claims 21 to 24,
wherein the network is an ordered or an unordered network.

26. The network of metal fibers according to one of the preceding claims 21 to 25,
wherein the network has open pores between the metal fibers of the plurality of metal fibers.

27. The network of metal fibers according to one of the preceding claims 19 to 24,
wherein points of contact (12) between the meal fibers are distributed in an unordered or ordered manner throughout the three-dimensional structure of the network.

28. Network of metal fibers, in particular a network according to one of claims 21 to 27, that is obtainable by the method according to one of the preceding claims 1 to 20.

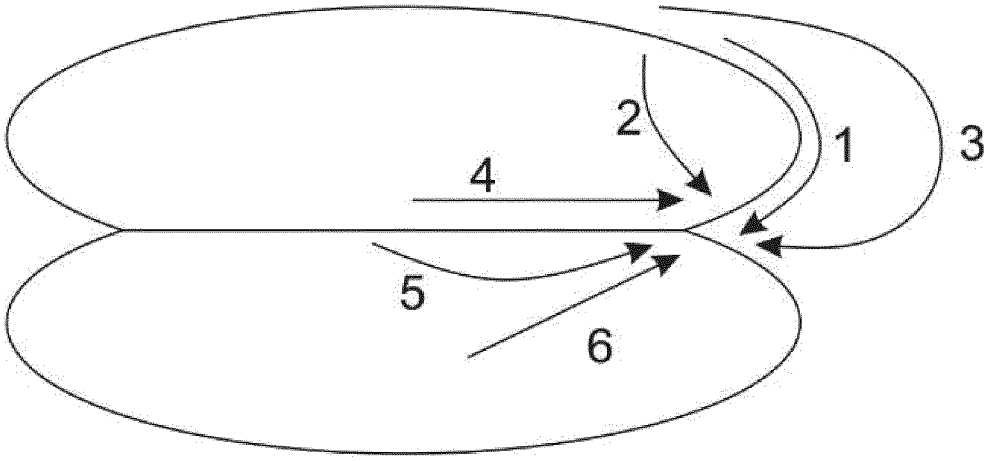

FIG. 1

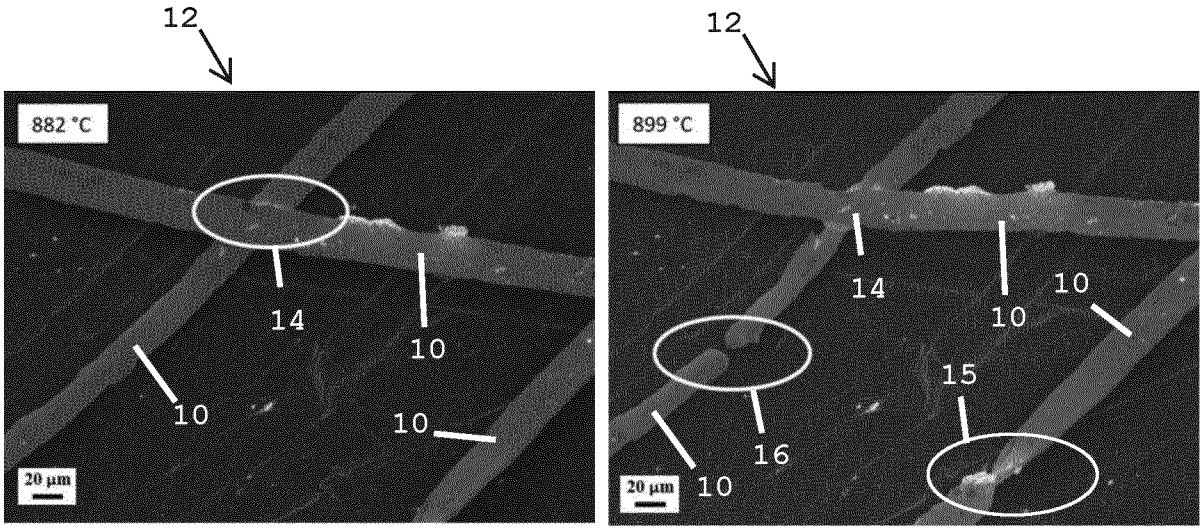

FIG. 2

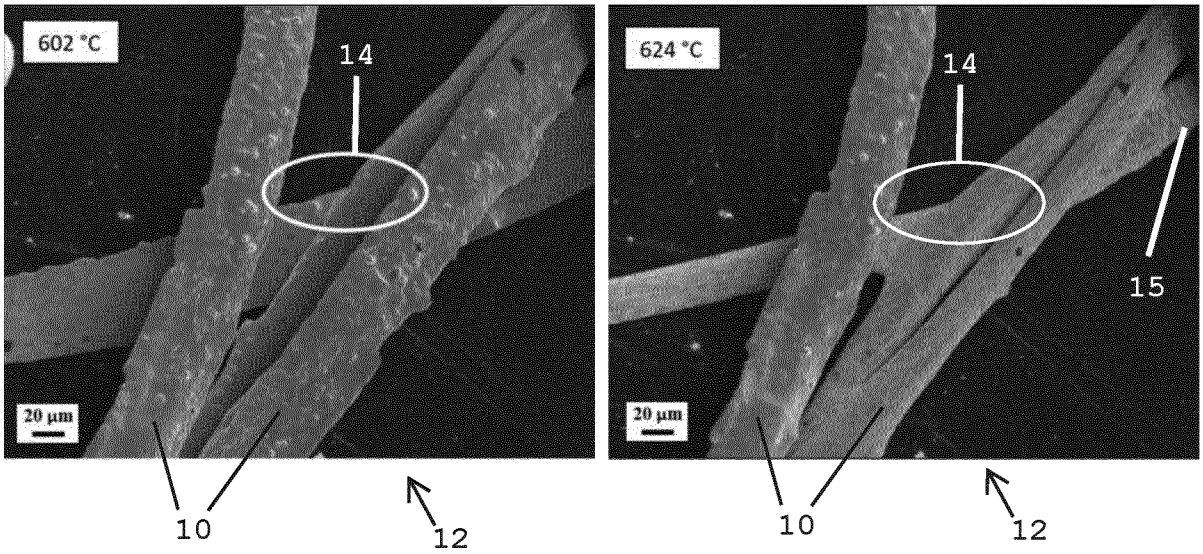

FIG. 3

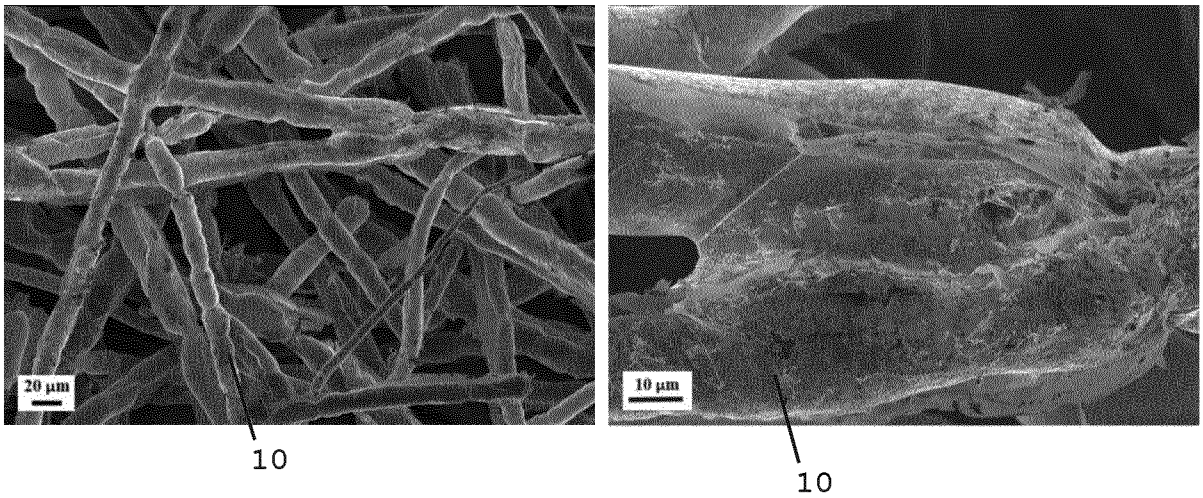

FIG. 4

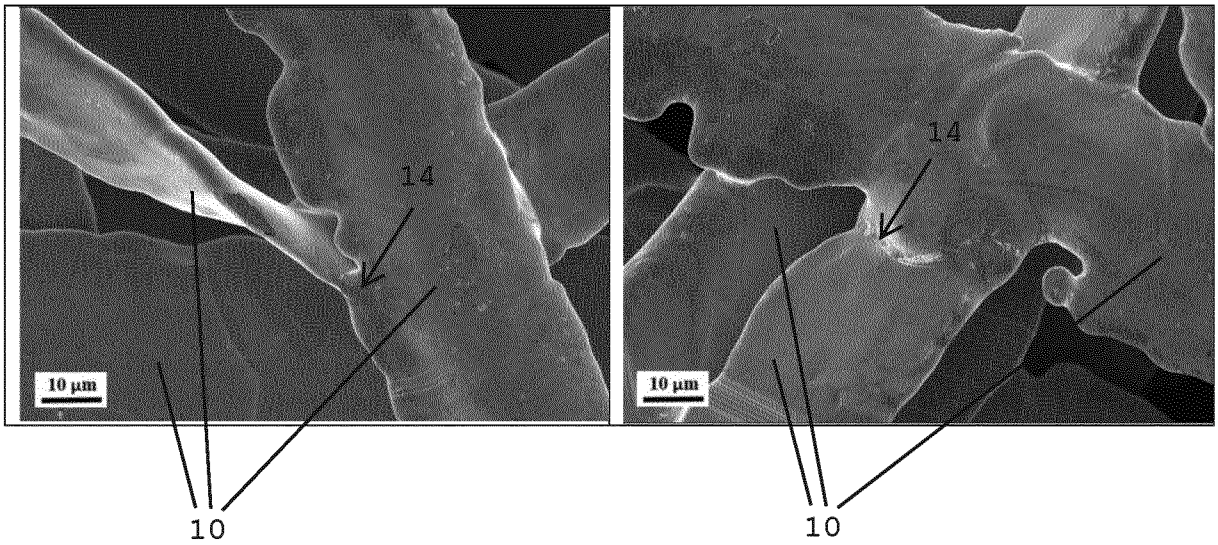

FIG. 5

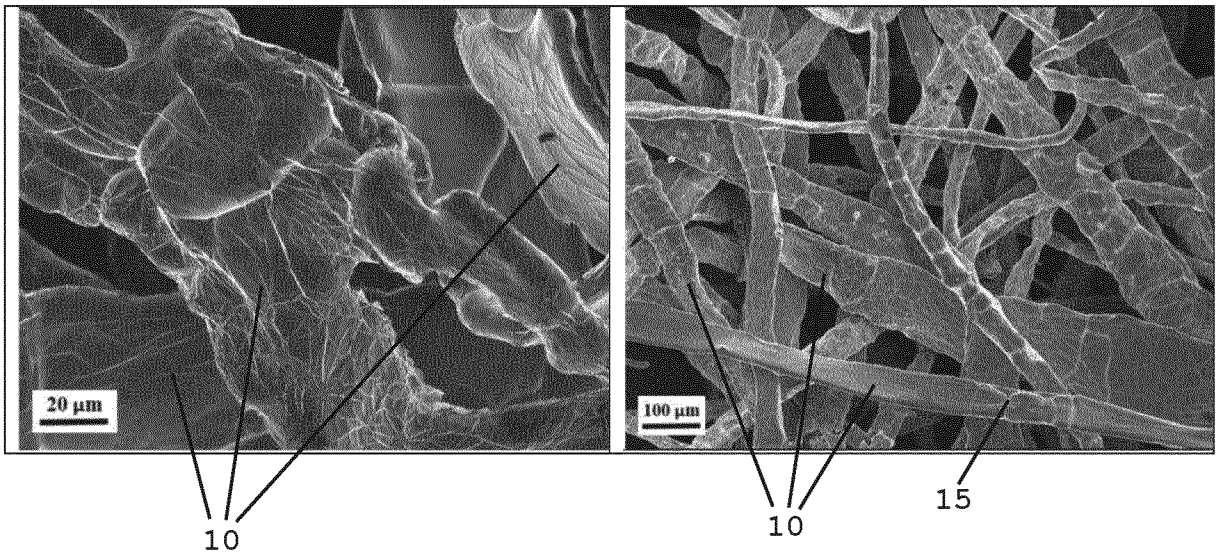

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/062435

A. CLASSIFICATION OF SUBJECT MATTER
INV. D04H1/4234 B01D39/10 B01D39/12 B01D39/20 B22F3/00
H01M4/04 H01M4/80
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
D04H H01M C22C B01D B22F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2020/016240 A1 (MAX PLANCK GESELLSCHAFT [DE]; UNIV STUTTGART [DE]) 23 January 2020 (2020-01-23) claims 1-18	1-28
A	WO 2016/075005 A1 (BEKAERT SA NV [BE]) 19 May 2016 (2016-05-19) paragraph [0030] paragraph [0045]; claims 1-15	1-28

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 January 2022	21/01/2022

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Demay, Stéphane

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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		KR 20170085497 A	24-07-2017
		US 2017239602 A1	24-08-2017
		WO 2016075005 A1	19-05-2016