

EXPANDED POLYPROPYLENE RESIN BEAD AND METHOD FOR PRODUCING SAME

FIELD OF THE INVENTION

[0001]

The present invention relates to an expanded polypropylene resin bead and a method for producing the same.

BACKGROUND OF THE INVENTION

[0002]

Expanded beads molded articles prepared by the in-mold molding of expanded polypropylene resin beads are excellent in chemical resistance, shock resistance, recovery properties from compressive set, etc. and as such, are utilized as shock absorbers, heat insulating materials, various packaging materials, and the like in a wide range of fields such as food containers, packaging or cushioning materials for electric and electronic parts, automobile bumper or interior members, building members such as residential heat insulating materials, and sundries.

[0003]

Expanded polypropylene resin beads molded articles are produced by the in-mold molding method which involves, for example, filling expanded polypropylene resin beads into a mold for molding, and heating the mold with a heating medium such as steam so that the expanded beads are secondarily expanded while their surfaces are melted and fusion bonded to each other so as to mold the expanded beads into the desired shape. In the in-mold molding of the expanded polypropylene resin beads, the temperature of heating with the heating medium is typically set in consideration of the melting point of the resin constituting a foamed layer.

[0004]

The expanded polypropylene resin beads are difficult to process by molding due to the crystallinity and heat resistance of the propylene resin and are therefore being studied for improvement in their molding processability. For example, JP 2004-68016 A describes a method for producing expanded polypropylene resin beads, including impregnating multi-layered resin particles with a blowing agent, followed by expansion, the multi-layered resin particles

each consisting of a core layer formed from a polypropylene resin, and an outer layer formed from a polypropylene resin, wherein a melting point of the polypropylene resin in the outer layer and a melting point of the polypropylene resin in the core layer have a specified relationship, and a thickness of the outer layer is equal to or smaller than a specified value. The expanded polypropylene resin beads obtained by this production method exert an effect of being excellent in fusion bonding properties among the expanded beads at a low mold heating temperature or molding pressure.

[0005]

However, the expanded polypropylene resin beads described in JP 2004-68016 A may be inferior in mold release properties depending on their molding conditions or the type of a base material resin. The mold release properties may be poor, particularly, when expanded beads having a low apparent density are used or when a mold heating temperature is high. Thus, expanded beads having favorable mold release properties in a wide mold heating temperature range are desired from the viewpoint of enhancing the productivity of expanded beads molded articles. In order to improve the mold release properties of expanded beads, for example, JP 2001-328135 A and JP 2002-172642 A each disclose a molding apparatus equipped with comb teeth in a mold or a movable member in molding space. For example, JP 2015-214110 A discloses a method for producing an expanded beads molded article using a mold in which a small hole or a slit having a cross-sectional shape with an opening area increased towards a surface to be contacted with expanded beads is formed on at least one of the inner wall surfaces of the mold.

[0007]

However, JP 2001-328135 A, JP 2002-172642 A, and JP 2015-214110 A require dedicated apparatuses. There is a demand for the realization of expanded polypropylene resin beads that have a wide mold heating temperature range which enables molding into expanded beads molded articles even when a versatile apparatus is used, and are excellent in mold release properties.

[0008]

Accordingly, an object of the present invention is to provide an expanded polypropylene resin bead that has a wide mold heating temperature range which enables molding, and is excellent in mold release properties, and a method for producing the same.

SUMMARY OF THE INVENTION

[0009]

The present inventors have found that the object can be attained by adopting a configuration given below, reaching the completion of the present invention.

Specifically, the present invention is as follows.

<1> An expanded polypropylene resin bead including a foamed core layer constituted of a polypropylene resin (C) and a cover layer constituted of a polypropylene resin (S), wherein the polypropylene resin (C) has a melting point T_{mc} of 125°C or higher and 170°C or lower, and the expanded polypropylene resin bead satisfies the following (1) to (4):

(1) the polypropylene resin (S) has a melting peak on the lower temperature side and a melting peak on the higher temperature side in a second time DSC curve obtained by heat flux differential scanning calorimetry when the resin is heated from 30°C to 200°C at a heating rate of 10°C/min, subsequently cooled from 200°C to 30°C at a cooling rate of 10°C/min, and heated again at a heating rate of 10°C/min;

(2) a peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is lower than the melting point T_{mc} of the polypropylene resin (C);

(3) a peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) is 138°C or higher; and

(4) a difference [$T_{mc} - T_{msh}$] between the melting point T_{mc} of the polypropylene resin (C) and the peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) is -10°C or more and 15°C or less.

<2> The expanded polypropylene resin bead according to <1>, wherein the peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is 125°C or higher and 135°C or lower.

<3> The expanded polypropylene resin bead according to <1> or <2>, wherein a difference [$T_{mc} - T_{msl}$] between the melting point T_{mc} of the polypropylene resin (C) and the peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is more than 0°C and 25°C or less.

<4> The expanded polypropylene resin bead according to any one of <1> to <3>, wherein a ratio $[\Delta H_h/\Delta H_t]$ of a heat of fusion (ΔH_h) of the melting peak on the higher temperature side of the polypropylene resin (S) to a total heat of fusion (ΔH_t) of the polypropylene resin (S) is 0.35 or more and 0.80 or less.

<5> The expanded polypropylene resin bead according to any one of <1> to <4>, wherein a difference $[T_{msh} - T_{msl}]$ between the peak top temperature T_{msh} of the melting peak on the higher temperature side and the peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is 10°C or more and 20°C or less.

<6> The expanded polypropylene resin bead according to any one of <1> to <5>, wherein the melting point T_{mc} of the polypropylene resin (C) is 130°C or higher and 150°C or lower.

<7> The expanded polypropylene resin bead according to any one of <1> to <6>, wherein the polypropylene resin (S) is a propylene copolymer that is composed mainly of a propylene component and includes an ethylene component and a butene component.

<8> The expanded polypropylene resin bead according to any one of <1> to <6>, wherein the expanded polypropylene resin bead has a bulk density of 10 kg/m³ or larger and 30 kg/m³ or smaller.

<9> A method for producing an expanded polypropylene resin bead, including the steps of: performing granulation into multi-layered resin particles each including a core layer constituted of a polypropylene resin (C) and a cover layer constituted of a polypropylene resin (S) and covering the core layer; dispersing the multi-layered resin particles in a dispersing medium in a closed vessel; impregnating the multi-layered resin particles dispersed in the dispersing medium with a blowing agent; and expanding the multi-layered resin particles containing the blowing agent to produce expanded beads, wherein the polypropylene resin (C) has a melting point T_{mc} of 125°C or higher and 170°C or lower, and the expanded polypropylene resin bead satisfies the following (1) to (4):

(1) the polypropylene resin (S) has a melting peak on the lower temperature side and a melting peak on the higher temperature side in a second time DSC curve obtained by heat flux differential scanning calorimetry when the resin is heated from 30°C to 200°C at a heating rate of 10°C/min, subsequently

cooled from 200°C to 30°C at a cooling rate of 10°C/min, and heated again at a heating rate of 10°C/min;

(2) a peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is lower than the melting point T_{mc} of the polypropylene resin (C);

(3) a peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) is 138°C or higher; and

(4) a difference [$T_{mc} - T_{msh}$] between the melting point T_{mc} of the polypropylene resin (C) and the peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) is -10°C or more and 15°C or less.

[0010]

The present invention can provide an expanded polypropylene resin bead that has a wide mold heating temperature range which enables molding, and is excellent in mold release properties in the entire range.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

FIG. 1 is a diagram showing the second time DSC curve of a polypropylene resin of a cover layer used in Example 1;

FIG. 2 is a diagram for illustrating how to determine a high-temperature peak of expanded beads; and

FIG. 3 is a diagram showing the second time DSC curve of a polypropylene resin of a cover layer used in Comparative Example 1.

DETAILED DESCRIPTION OF THE INVENTION

[0012]

[Expanded polypropylene resin bead]

The expanded polypropylene resin bead of the present invention (hereinafter, also simply referred to as the expanded polypropylene resin bead or the expanded bead) is an expanded polypropylene resin bead including a foamed core layer constituted of a polypropylene resin (C) (hereinafter, also simply referred to as the foamed core layer), and a cover layer constituted of a polypropylene resin (S) (hereinafter, also simply referred to as the cover layer), wherein the polypropylene resin (C) has a melting point T_{mc} of 125°C or higher

and 170°C or lower, and the expanded polypropylene resin bead satisfies the following (1) to (4):

(1) the polypropylene resin (S) has a melting peak on the lower temperature side and a melting peak on the higher temperature side in a second time DSC curve obtained by heat flux differential scanning calorimetry when the resin is heated from 30°C to 200°C at a heating rate of 10°C/min, subsequently cooled from 200°C to 30°C at a cooling rate of 10°C/min, and heated again at a heating rate of 10°C/min;

(2) a peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is lower than the melting point T_{mc} of the polypropylene resin (C);

(3) a peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) is 138°C or higher; and

(4) a difference [$T_{mc} - T_{msh}$] between the melting point T_{mc} of the polypropylene resin (C) and the peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) is -10°C or more and 15°C or less.

[0013]

The expanded polypropylene resin bead of the present invention is an expanded bead having a multi-layered structure where the polypropylene resin (C) and the polypropylene resin (S) having a specified relationship constitute a foamed core layer and a cover layer, respectively, and thereby has a wide molding pressure range which enables molding, and is excellent in moldability and also excellent in mold release properties.

Specifically, it has been found that use of an expanded polypropylene resin bead that satisfies the aforementioned (1) to (4) is preferred for achieving both moldability and mold release properties.

Mold release properties tend to be impaired in conventional expanded beads provided with a cover layer constituted of a polypropylene resin having a lower melting point than that of a polypropylene resin constituting a foamed core layer in order to improve fusion bonding properties. Particularly, under a condition of a high mold heating temperature, mold release properties tend to be markedly impaired, probably because the resin of the cover layer softens and easily adheres to a mold for molding. Furthermore, mold release properties also tend to be markedly impaired when expanded beads having a low apparent

density are used. In the present invention, it has been found that the expanded polypropylene resin bead which satisfies the aforementioned (1) to (4) is excellent in fusion bonding properties and can achieve both moldability and mold release properties.

[0014]

<Cover layer>

The cover layer of the expanded polypropylene resin bead covers a foamed core layer. The cover layer preferably covers substantially the whole outer surface of the foamed core layer, and may completely cover the whole outer surface of the foamed core layer. Specifically, the cover layer preferably covers 50% or more of the area of the surface of the core layer, more preferably 70% or more of the area, and may cover substantially 100% of the area or may cover 90% or less of the area.

[0015]

The cover layer is preferably in a non-foamed state or in a substantially non-foamed state, more preferably in a non-foamed state, from the viewpoint of the appearance of an expanded polypropylene resin beads molded article obtained using the expanded polypropylene resin bead of the present invention (hereinafter, also referred to as the expanded polypropylene resin beads molded article or the expanded beads molded article). The non-foamed state or the substantially non-foamed state means that a cell structure is almost absent. This state also encompasses the state where once formed cells are fractured so that the cells vanish. Alternatively, the cover layer may be in a slightly foamed state without inhibiting the object and advantageous effects of the present invention.

[0016]

(Polypropylene resin (S))

The cover layer of the expanded polypropylene resin bead is constituted of a polypropylene resin (S). The polypropylene resin used herein refers to a polymer having a propylene-derived constituent unit content of 50% by mass or more. Examples of the polypropylene resin include propylene homopolymers, propylene copolymers and mixtures thereof. The polypropylene resin may also contain other polymers such as resins or elastomers other than the polypropylene. The content thereof is preferably 20% by mass or less, more

preferably 15% by mass or less, further preferably 10% by mass or less, particularly preferably 5% by mass or less.

[0017]

<<(1) Double peak>>

The polypropylene resin (S) has a melting peak on the lower temperature side and a melting peak on the higher temperature side in a DSC curve obtained in accordance with JIS K 7121: 1987 by adopting "(2) the case of measuring a fusion temperature after performing a certain heat treatment" for conditioning, and heating a conditioned test piece from 30°C to 200°C at a heating rate of 10°C/min. Specifically, the polypropylene resin (S) has a melting peak on the lower temperature side and a melting peak on the higher temperature side in a second time DSC curve obtained by heat flux differential scanning calorimetry when the resin conditioned at 23°C for 24 hours or longer in a 50% RH atmosphere is used as a test piece and this resin is heated from 30°C to 200°C at a heating rate of 10°C/min, subsequently cooled from 200°C to 30°C at a cooling rate of 10°C/min, and heated again at a heating rate of 10°C/min. In this context, to have a melting peak on the lower temperature side and a melting peak on the higher temperature side means that the melting peak on the lower temperature side and the melting peak on the higher temperature side have the peak top temperatures (melting points) of peaks different from each other and their respective heat of fusions are 10 J/g or higher. A method for measuring the heat of fusions will be mentioned later. The melting peak on the lower temperature side and the melting peak on the higher temperature side may partially overlap with each other. The melting peak on the lower temperature side and the melting peak on the higher temperature side in the second time DSC curve of the polypropylene resin (S) is also collectively referred to as the double peak herein.

When three or more melting peaks appear in the second time DSC curve of the polypropylene resin (S), a melting peak that has a peak top temperature on the lowest temperature side and has a heat of fusion of 10 J/g or higher is regarded as the melting peak on the lower temperature side, and a melting peak that has a peak top temperature on the highest temperature side and has a heat of fusion of 10 J/g or higher is regarded as the melting peak on the higher temperature side.

When the polypropylene resin (S) lacks the melting peak on the lower temperature side and the melting peak on the higher temperature side (double peak) and has a single melting peak in the second time DSC curve, the expanded polypropylene resin bead might be unable to achieve both moldability and mold release properties.

[0018]

<<(2) Peak top temperature Tmsl of melting peak on lower temperature side>>

A peak top temperature Tmsl of the melting peak on the lower temperature side of the polypropylene resin (S) is lower than a melting point Tmc of the polypropylene resin (C) mentioned later. Tmsl that is lower than Tmc attains excellent fusion bonding properties even at a low mold heating temperature and improves moldability. From a similar viewpoint, Tmsl is preferably 135°C or lower, more preferably 132°C or lower, further preferably 130°C or lower. On the other hand, Tmsl is preferably 125°C or higher, more preferably 126°C or higher, further preferably 127°C or higher, from the viewpoint of more improving the mold release properties of the expanded polypropylene resin bead (hereinafter, also simply referred to as the mold release properties).

[0019]

<<(3) Peak top temperature Tmsh of melting peak on higher temperature side>>

A peak top temperature Tmsh of the melting peak on the higher temperature side of the polypropylene resin (S) is 138°C or higher. If Tmsh is lower than 138°C, the mold release properties of the expanded bead might be impaired, particularly, under a condition of a high mold heating temperature. From this viewpoint, Tmsh is preferably 139°C or higher, more preferably 140°C or higher, further preferably 141°C or higher. Tmsh is preferably 170°C or lower, more preferably 160°C or lower, further preferably 155°C or lower, still further preferably 150°C or lower, still further preferably 145°C or lower, from the viewpoint of more improving moldability.

[0020]

<<(4) Difference between melting point Tmc of polypropylene resin (C) and Tmsh>>

The difference [Tmc - Tmsh] between the melting point Tmc of the polypropylene resin (C) mentioned later and the peak top temperature Tmsh of the melting peak on the higher temperature side of the polypropylene resin (S) is -10°C or more and 15°C or less. If the difference [Tmc - Tmsh] is more than

15°C, the mold release properties of the expanded bead might be impaired when a resin having a relatively high melting point is used. From this viewpoint, the difference $[T_{mc} - T_{msh}]$ is preferably 12°C or less, more preferably 10°C or less, further preferably 7°C or less. If the difference $[T_{mc} - T_{msh}]$ is less than -10°C, the expanded bead might be unable to achieve both moldability and mold release properties. The difference $[T_{mc} - T_{msh}]$ is preferably -8°C or more, further preferably -5°C or more, from the viewpoint of improving mold release properties while preventing reduction in moldability.

[0021]

<<Difference between melting point T_{mc} of polypropylene resin (C) and T_{msl} >>

The difference $[T_{mc} - T_{msl}]$ between the melting point T_{mc} of the polypropylene resin (C) mentioned later and the peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is more than 0°C from the viewpoint of moldability, as mentioned above. The difference $[T_{mc} - T_{msl}]$ is more preferably 5°C or more, further preferably 10°C or more, from the viewpoint of more improving the moldability of the expanded bead. On the other hand, the difference $[T_{mc} - T_{msl}]$ is preferably 25°C or less, more preferably 22°C or less, further preferably 20°C or less, from the viewpoint of more improving mold release properties and from the viewpoint of suppressing the separate between the foamed core layer and the cover layer.

[0022]

<<Difference between T_{msh} and T_{msl} >>

The difference $[T_{msh} - T_{msl}]$ between the peak top temperature T_{msh} of the melting peak on the higher temperature side and the peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is preferably 10°C or more, more preferably 13°C or more, and preferably 20°C or less, more preferably 17°C or less, further preferably 15°C or less, from the viewpoint of achieving both moldability and mold release properties in a well-balanced manner.

[0023]

<<Ratio of heat of fusion ΔH_h of melting peak on higher temperature side to total heat of fusion ΔH_t >>

The ratio $[\Delta H_h / \Delta H_t]$ of heat of fusion ΔH_h of the melting peak on the higher temperature side to total heat of fusion ΔH_t of the polypropylene resin (S) is preferably 0.35 or more, more preferably 0.38 or more, further preferably 0.40

or more, and preferably 0.80 or less, more preferably 0.70 or less, further preferably 0.60 or less, still further preferably 0.50 or less, from the viewpoint of achieving both moldability and mold release properties in a well-balanced manner.

[0024]

The heat of fusion ΔH_l of the melting peak on the lower temperature side, the heat of fusion ΔH_h of the melting peak on the higher temperature side, and the total heat of fusion ΔH_t of the polypropylene resin (S) are determined, using a DSC curve as exemplified in FIG. 1, as follows: a point at a temperature of 80°C on the DSC curve is defined as α , and a point corresponding to an end temperature of melting on the DSC curve is defined as β . A straight line parallel to the ordinate of the graph is drawn from point γ , on the DSC curve, corresponding to the valley between melting peak P_l on the lower temperature side and melting peak P_h on the higher temperature side, and a point intersecting with a straight line (α - β) which connects the point α and the point β is defined as δ . If the point γ , on the DSC curve, corresponding to the valley between melting peak P_l on the lower temperature side and melting peak P_h on the higher temperature side is not clear due to, for example, the partial overlap between the melting peak on the lower temperature side and the melting peak on the higher temperature side, the position of the point γ can be determined with reference to the differential curve of DSC (DDSC) near that temperature. The point γ represents 0 in DDSC.

An area (A) of the melting peak P_l on the lower temperature side is regarded as the heat of fusion ΔH_l of the melting peak P_l on the lower temperature side, and determined as the area of a portion surrounded by the DSC curve depicting the melting peak P_l on the lower temperature side, a line segment (α - δ) and a line segment (γ - δ).

An area (B) of the melting peak P_h on the higher temperature side is regarded as the heat of fusion ΔH_h of the melting peak P_h on the higher temperature side, and determined as the area of a portion surrounded by the DSC curve depicting the melting peak P_h on the higher temperature side, a line segment (δ - β) and the line segment (γ - δ).

The total heat of fusion ΔH_t is defined as the total sum [$A + B$, i.e., $\Delta H_l + \Delta H_h$] of the area (A) of the melting peak P_l on the lower temperature side and the area (B) of the melting peak P_h on the higher temperature side, and in FIG. 1, is

the area of a portion surrounded by the straight line (α - β) and the DSC curve at a zone from the point α to the point β .

[0025]

<< ΔH_l >>

The heat of fusion ΔH_l of the melting peak on the lower temperature side of the polypropylene resin (S) is preferably 25 J/g or higher, more preferably 30 J/g or higher, further preferably 35 J/g or higher, from the viewpoint of more enhancing moldability, and is preferably 50 J/g or lower, more preferably 45 J/g or lower, further preferably 43 J/g or lower, from the viewpoint of more reliably securing mold release properties.

[0026]

<< ΔH_h >>

The heat of fusion ΔH_h of the melting peak on the higher temperature side of the polypropylene resin (S) is preferably 15 J/g or higher, more preferably 21 J/g or higher, further preferably 26 J/g or higher, still further preferably 30 J/g or higher, from the viewpoint of more enhancing mold release properties, and is preferably 45 J/g or lower, more preferably 40 J/g or lower, further preferably 35 J/g or lower, from the viewpoint of more reliably securing moldability.

[0027]

<< ΔH_t >>

The total heat of fusion ΔH_t of the polypropylene resin (S) is preferably 57 J/g or higher, more preferably 65 J/g or higher, further preferably 70 J/g or higher, and preferably 85 J/g or lower, more preferably 80 J/g or lower, further preferably 75 J/g or lower, from the viewpoint of achieving both moldability and mold release properties in a well-balanced manner.

[0028]

<<Melt flow rate (MFR)>>

MFR of the polypropylene resin (S) is preferably 2 g/10 min or more, more preferably 4 g/10 min or more, further preferably 5 g/10 min or more, and preferably 10 g/10 min or less, more preferably 9 g/10 min or less, further preferably 8 g/10 min or less, from the viewpoint of easily forming the cover layer and suppressing its separate from the foamed core layer.

MFR of the polypropylene resin (S) is measured under conditions involving a temperature of 230°C and a load of 2.16 kg in accordance with JIS K 7210-1: 2014.

[0029]

The polypropylene resin (S) is not particularly limited as long as the polypropylene resin (S) satisfies the aforementioned (1) to (3) and satisfies the aforementioned relationship (4) with the melting point T_{mc} of the polypropylene resin (C). The polypropylene resin (S) is preferably a propylene copolymer that is composed mainly of a propylene component and includes an ethylene component and a butene component.

[0030]

When the polypropylene resin (S) is a propylene copolymer that is composed mainly of a propylene component and includes an ethylene component and a butene component, the content of the ethylene component in the copolymer is preferably 3.0% by mass or more and 6.0% by mass or less, more preferably 3.5% by mass or more and 5.5% by mass or less, further preferably 4.0% by mass or more and 5.0% by mass or less. The content of the butene component in the copolymer is preferably 5.0% by mass or more and 18% by mass or less, more preferably 7.5% by mass or more and 15% by mass or less, further preferably 9.0% by mass or more and 12% by mass or less. In this context, the total content of the propylene component, the ethylene component, and the butene component is 100% by mass. The content of each monomer component in the copolymer can be measured by IR spectroscopy. The propylene copolymer having the contents of the ethylene component and the butene component that fall within the aforementioned ranges easily has a crystal structure where the melting peak on the lower temperature side and the melting peak on the higher temperature side appear such that the copolymer satisfies the aforementioned (1) to (4).

From a similar viewpoint, the ratio [butene component content/ethylene component content] between the butene component content and the ethylene component content is preferably 1.5 or more, more preferably 1.8 or more, further preferably 2.0 or more, and preferably 5.0 or less, more preferably 4.0 or less, further preferably 3.0 or less.

In the present invention, examples of the resin that may be used as the polypropylene resin (S) include FL7540L and FL7320L manufactured by The Polyolefin Company (Singapore) Pte Ltd. (TPC).

[0031]

The polypropylene resin (S) may contain an additive without inhibiting the object and advantageous effects of the present invention.

[0032]

<Foamed core layer>

The foamed core layer of the expanded polypropylene resin bead is constituted of a polypropylene resin (C). The closed cell content of the expanded bead is preferably 80% or more, more preferably 90% or more, further preferably 95% or more, from the viewpoint of improving the moldability of the expanded bead and the rigidity of the molded article, etc. The closed cell content of the expanded beads can be measured using an air comparison-type pycnometer in accordance with procedure C of ASTM-D2856-70.

[0033]

(Polypropylene resin (C))

<<melting point T_{mc}>>

A melting point T_{mc} of the polypropylene resin (C) is 125°C or higher, preferably 130°C or higher, more preferably 135°C or higher, further preferably 140°C or higher, still further preferably 145°C or higher, and 170°C or lower, preferably 165°C or lower, more preferably 160°C or lower, further preferably 155°C or lower, still further preferably 150°C or lower, from the viewpoint of the rigidity, heat resistance, etc. of the expanded beads molded article. According to the present invention, the expanded polypropylene resin bead having the polypropylene resin (S) constituting the cover layer and the polypropylene resin (C) having the melting point T_{mc} in the aforementioned wide range can achieve both moldability and mold release properties. When conventional expanded beads having a polypropylene resin having a particularly high melting point as a base material resin are provided with a cover layer in order to improve fusion bonding properties, it is difficult to attain favorable mold release properties in the entire mold heating temperature range which enables molding. The present invention can achieve both moldability and mold release properties even when a polypropylene resin having a relatively high melting point is used as the foamed core layer.

The melting point T_{mc} of the polypropylene resin (C) is determined as the peak top temperature of a melting peak associated with the melting of the resin on a DSC curve obtained in accordance with JIS K 7121: 1987 by adopting "(2) the case of measuring a fusion temperature after performing a certain heat treatment" for the conditioning of a test piece, and heating a conditioned test piece from 30°C to 200°C at a heating rate of 10°C/min. When a plurality of

melting peaks appear in the DSC curve, the peak top temperature of a melting peak having the largest area is regarded as the melting point. In this case, the area of each melting peak can be determined in the same manner as in the heat of fusions of the polypropylene resin (S).

[0034]

<<Flexural modulus>>

The flexural modulus of the polypropylene resin (C) is preferably 500 MPa or more, more preferably 600 MPa or more, further preferably 700 MPa or more, still further preferably 800 MPa or more, and preferably 1600 MPa or less, more preferably 1300 MPa or less, further preferably 1100 MPa or less, from the viewpoint of achieving both moldability and mold release properties while maintaining the mechanical strength of the expanded beads molded article.

The flexural modulus of the polypropylene resin can be determined in accordance with JIS K 7171: 2016.

[0035]

<<MFR>>

MFR of the polypropylene resin (C) is preferably 2 g/10 min or more, more preferably 4 g/10 min or more, further preferably 5 g/10 min or more, and preferably 15 g/10 min or less, more preferably 12 g/10 min or less, further preferably 10 g/10 min or less, from the viewpoint of expandability.

MFR of the polypropylene resin (C) is a value measured under conditions involving 230°C and a load of 2.16 kg in the same manner as in MFR of the polypropylene resin (S).

[0036]

The polypropylene resin (C) is not particularly limited as long as the polypropylene resin (C) has the melting point T_{mc} that falls within the aforementioned range, satisfies the aforementioned relationship (2) with the peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S), and satisfies the aforementioned relationship (4) with the peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S). The polypropylene resin (C) is preferably a polypropylene copolymer or a mixture of a polypropylene homopolymer and a propylene copolymer.

[0037]

The polypropylene copolymer is preferably an ethylene-propylene copolymer, an ethylene-propylene-butene copolymer, or a mixture of any of these copolymers with a polypropylene homopolymer, more preferably an ethylene-propylene copolymer or an ethylene-propylene-butene copolymer, further preferably an ethylene-propylene copolymer.

[0038]

The polypropylene resin (C) may contain other polymers such as resins other than the propylene homopolymer or the propylene copolymer, and elastomers without inhibiting the object and advantageous effects of the present invention. The content of these other polymers in the polypropylene resin (C) is preferably 20% by mass or less, more preferably 10% by mass or less, further preferably 5% by mass or less, still further preferably 3% by mass or less, most preferably 0% by mass, i.e., the polypropylene resin (C) preferably consists of a polypropylene resin as a polymer.

[0039]

The foamed core layer can be supplemented, if necessary, with additives such as a cell adjusting agent, a flame retardant, a flame retardant synergist, a cell nucleating agent, a plasticizer, an antistatic agent, an antioxidant, a UV absorbing agent, a light stabilizer, a conductive filler, and an antimicrobial agent.

[0040]

The mass ratio (% ratio by mass) between the resin constituting the foamed core layer and the resin constituting the cover layer is preferably from 99.5:0.5 to 80:20, more preferably from 99:1 to 85:15, further preferably from 97:3 to 90:10, from the viewpoint of enhancing moldability and mold release properties while maintaining the rigidity of the molded article. The mass ratio is indicated by the resin constituting the foamed core layer: the resin constituting the cover layer.

[0041]

[Physical properties of expanded polypropylene resin bead]

<Bulk density>

The bulk density of the expanded polypropylene resin bead is preferably 10 kg/m³ or larger, more preferably 15 kg/m³ or larger, and preferably 100 kg/m³ or smaller, more preferably 70 kg/m³ or smaller, further preferably 50 kg/m³ or smaller, still further preferably 30 kg/m³ or smaller, particularly preferably 20 kg/m³ or smaller, from the viewpoint of achieving both mechanical strength and

lightness in weight of the expanded beads molded article in a well-balanced manner.

The bulk density of the expanded bead is determined as follows: the bulk density of the expanded bead is determined by taking out expanded beads from a group of expanded beads at random, placing the expanded beads in a 1-liter capacity graduated cylinder such that many expanded beads are contained in a spontaneously deposited state up to the scale marking of 1 L, dividing mass $W1$ [g] of the contained expanded beads by volume $V1$ (1 [L]) of the contents ($W1 / V1$), and converting the unit to $[\text{kg}/\text{m}^3]$.

The mold release properties of conventional expanded beads having a low bulk density are easily impaired. According to the present invention, even the expanded bead having a low bulk density of, for example, $30 \text{ kg}/\text{m}^3$ or smaller, has favorable mold release properties.

[0042]

The expanded bead preferably has a crystal structure where a melting peak ascribable to melting intrinsic for a polypropylene resin (i.e., a resin-intrinsic peak), and at least one melting peak (i.e., a high-temperature peak) on the higher temperature side therefrom appear in a DSC curve obtained when the expanded bead is heated from 23°C to 200°C at a heating rate of $10^\circ\text{C}/\text{min}$. The DSC curve is obtained by differential scanning calorimetry (DSC) using 1 to 3 mg of expanded beads as a test sample in accordance with JIS K 7121: 1987. The resin-intrinsic peak refers to a melting peak ascribable to melting intrinsic for the polypropylene resin constituting the foamed core layer, and is presumably caused by endotherm at the time of the melting of the original crystals of the polypropylene resin. On the other hand, the melting peak on the higher temperature side (i.e., the high-temperature peak) from the resin-intrinsic peak refers to a melting peak that appears on the higher temperature side from the resin-intrinsic peak in the DSC curve. When this high-temperature peak appears, the resin is predicted to have secondary crystals. Only the melting peak ascribable to melting intrinsic for the polypropylene resin constituting the expanded bead is seen in a DSC curve obtained when the expanded bead is heated from 23°C to 200°C at a heating rate of $10^\circ\text{C}/\text{min}$ (i.e., the first heating), then cooled from 200°C to 23°C at a cooling rate of $10^\circ\text{C}/\text{min}$, and then heated again from 23°C to 200°C at a heating rate of $10^\circ\text{C}/\text{min}$ (i.e., the second heating). Therefore, the resin-intrinsic peak can be distinguished from the high-

temperature peak. Although the peak top temperature of this resin-intrinsic peak may differ to a certain extent between the first heating and the second heating, the difference is usually within 5°C.

[0043]

< Heat of fusion ΔH_2 of high-temperature peak >

A heat of fusion ΔH_2 of the high-temperature peak of the expanded polypropylene resin bead is preferably 5 J/g or higher, more preferably 8 J/g or higher, further preferably 10 J/g or higher, and preferably 40 J/g or lower, more preferably 30 J/g or lower, further preferably 20 J/g or lower, still further preferably 18 J/g or lower, from the viewpoint of the mechanical strength and moldability of the expanded bead.

[0044]

A method for measuring the heat of fusion ΔH_2 of the high-temperature peak of the expanded polypropylene resin bead will be described using a DSC curve as exemplified in FIG. 2. Straight line L1 is obtained by connecting point α at a temperature of 80°C on the DSC curve with point β at an end temperature of melting T of the expanded bead. Next, straight line L2 parallel to the ordinate of the graph is drawn from point γ , on the DSC curve, corresponding to the valley between resin-intrinsic peak P_1 and high-temperature peak P_2 described above, and a point at which the straight line L1 and the straight line L2 intersect with each other is defined as δ . The point γ can also be regarded as the local maximum point present between the resin-intrinsic peak P_1 and the high-temperature peak P_2 .

An area (2) of the high-temperature peak P_2 of the expanded bead is regarded as the heat of fusion ΔH_2 of the high-temperature peak P_2 , and determined as the area of a portion surrounded by the DSC curve depicting the high-temperature peak P_2 , a line segment (δ - β) and a line segment (γ - δ). An area (1) of the resin-intrinsic peak P_1 of the expanded bead is regarded as the heat of fusion ΔH_1 of the resin-intrinsic peak P_1 , and determined as the area of a portion surrounded by the DSC curve depicting the resin-intrinsic peak P_1 , a line segment (α - δ) and the line segment (γ - δ).

[0045]

[Method for producing expanded polypropylene resin bead]

A method for producing an expanded polypropylene resin bead is not particularly limited, and the expanded polypropylene resin bead can be produced by, for example, a method including the following steps (A) to (D):

step (A): a granulation step of melt kneading each of the polypropylene resin (C) constituting the core layer and the polypropylene resin (S) constituting the cover layer, coextruding the resultant in a strand-like form, followed by cutting to provide multi-layered resin particles each having a core layer in a non-foamed state and a cover layer covering the core layer;

step (B): a dispersion step of dispersing the multi-layered resin particles in a dispersing medium in a closed vessel;

step (C): a blowing agent impregnation step of impregnating the multi-layered resin particles with a blowing agent; and

step (D): an expansion step of releasing the expandable multi-layered resin particles impregnated with the blowing agent together with the dispersing medium from the closed vessel into an atmosphere having a pressure lower than the internal pressure of the closed vessel, thereby foaming at least the core layer into a foamed core layer to produce expanded beads.

[0046]

<Step (A)>

In the step (A), for example, an extruder having an extruder for core layer formation, an extruder for cover layer formation, and a die for multi-layered strand formation installed on the outlet side of these extruders, can be used. The polypropylene resin (C) constituting the core layer, and an additive to be optionally added are fed to the extruder for core layer formation, and melt kneaded into a core layer-forming melt kneaded material. The polypropylene resin (S) constituting the cover layer, and an additive to be optionally added are fed to the extruder for cover layer formation, and melt kneaded into a cover layer-forming melt kneaded material. The core layer-forming melt kneaded material and the cover layer-forming melt kneaded material are introduced into the die for multi-layered strand formation, and combined to form a composite that consists of a core layer in a non-foamed state and a cover layer in a non-foamed state covering the core layer, and has a core-sheath structure. Then, the composite is extruded in a strand-like form from small holes of the die annexed in the tip of the extruder, cooled in water, and then cut in a pelletizer so as to attain a predetermined mass (strand cut method). In this way, multi-layered resin

particles having a core layer in a non-foamed state and a cover layer covering the core layer can be obtained. In addition to the aforementioned method, for example, an underwater cut method of extruding and cutting the composite in water, or a hot cut method of cutting the composite immediately after extrusion into air may be adopted as a method for cutting the extruded composite.

[0047]

(Particle sizes of multi-layered resin particles)

The particle sizes of the multi-layered resin particles are preferably from 0.1 to 3.0 mm, more preferably from 0.3 to 1.5 mm.

[0048]

(Mass of multi-layered resin particles)

The average mass of the multi-layered resin particles is preferably adjusted to from 0.1 to 20 mg, more preferably from 0.2 to 10 mg, further preferably from 0.3 to 5 mg, still further preferably from 0.4 to 2 mg.

[0049]

(Mass ratio between cover layer and core layer)

In producing the multi-layered resin particles, the mass ratio between the cover layer and the core layer in a non-foamed state (cover layer/core layer) is preferably from 0.5/99.5 to 20/80, more preferably from 1/99 to 15/85, further preferably from 3/97 to 10/90, from the viewpoint of the fusion bonding properties of the expanded bead.

[0050]

(Additive)

The multi-layered resin particles having the core layer in a non-foamed state and the cover layer can be supplemented, if necessary, with additives such as a cell controlling agent, a flame retardant, a flame retardant synergist, a cell nucleating agent, a plasticizer, an antistatic agent, an antioxidant, a UV absorbing agent, a light stabilizer, a conductive filler, and an antimicrobial agent. These additives, if added, can be added in the step (A). Examples of the cell controlling agent include: inorganic powders such as talc, mica, zinc borate, calcium carbonate, silica, titanium oxide, gypsum, zeolite, borax, aluminum hydroxide, and carbon; and organic powders such as phosphate nucleating agents, phenol nucleating agents, amine nucleating agents, and polyethylene fluoride resin powders. In the case of adding a cell controlling, the content of the cell controlling agent in the multi-layered resin particles is preferably from

0.01 to 1 part by mass based on 100 parts by mass of the multi-layered resin particles.

[0051]

<Step (B)>

In the step (B), the multi-layered resin particles can be dispersed in a dispersing medium using, for example, a stirrer, in a vessel, for example, an autoclave, which is closable and endures heating and pressurization.

[0052]

The dispersing medium is not particularly limited as long as the dispersing medium does not dissolve the multi-layered resin particles. Examples thereof include water and alcohols such as ethylene glycol, glycerin, methanol, and ethanol. Among them, water is preferred.

[0053]

In the step (B), it is preferred for preventing the fusion bonding among the multi-layered resin particles to further add a dispersant to the dispersing medium. Examples of the dispersant include: organic dispersants such as polyvinyl alcohol, polyvinylpyrrolidone, and methylcellulose; and poorly soluble inorganic salts such as aluminum oxide, zinc oxide, kaolin, mica, magnesium phosphate, and tricalcium phosphate. These dispersants can be used singly or in combination of two or more types. Among them, a poorly soluble inorganic salt is preferred, and kaolin is more preferred, because of easy handling. In the case of adding a dispersant, the dispersant is preferably added at from approximately 0.001 to 5 parts by mass based on 100 parts by mass of the multi-layered resin particles.

[0054]

A surfactant may be further added to the dispersing medium. Examples of the surfactant include sodium dodecyl benzenesulfonate, sodium alkylsulfonate, sodium oleate, sodium lauryl sulfate, sodium polyoxyethylene alkyl ether phosphate, sodium polyoxyethylene alkyl ether sulfate, and anionic surfactants and nonionic surfactants which are generally used in suspension polymerization. In the case of adding a surfactant, the surfactant is preferably added at from approximately 0.001 to 1 part by mass based on 100 parts by mass of the multi-layered resin particles.

[0055]

<Step (C)>

In the step (C), the multi-layered resin particles can be heated to, for example, a temperature equal to or higher than the softening temperature of the polypropylene resin (C) constituting the core layer, and impregnated with a blowing agent to obtain expandable multi-layered resin particles.

[0056]

The blowing agent is not particularly limited as long as the blowing agent can expand the multi-layered resin particles. Examples of the blowing agent include: inorganic physical blowing agents such as air, nitrogen, carbon dioxide, argon, helium, oxygen, and neon; and organic physical blowing agents including aliphatic hydrocarbons such as propane, normal butane, isobutane, normal pentane, isopentane, and normal hexane, alicyclic hydrocarbons such as cyclohexane and cyclopentane, halogenated hydrocarbons such as chlorofluoromethane, trifluoromethane, 1,1-difluoroethane, 1,1,1,2-tetrafluoroethane, methyl chloride, ethyl chloride, and methylene chloride, and dialkyl ethers such as dimethyl ether, diethyl ether, and methyl ethyl ether. Among them, an inorganic physical blowing agent which does not destroy the ozone layer and is inexpensive is preferred. Nitrogen, air, and carbon dioxide are more preferred, and carbon dioxide is particularly preferred. These blowing agents are used singly or in combination of two or more types.

[0057]

The amount of the blowing agent added is determined in consideration of the desired bulk density of the expanded bead, the type of the polypropylene resin, the type of the blowing agent, etc., and is usually preferably 5 to 50 parts by mass of the organic physical blowing agent or preferably 0.1 to 30 parts by mass, more preferably 0.5 to 15 parts by mass, of the inorganic physical blowing agent based on 100 parts by mass of the multi-layered resin particles.

[0058]

The heating temperature in the step (C) is preferably equal to or higher than the melting point of the polypropylene resin (C) and equal to or lower than the melting point + 80°C and specifically, preferably from 100°C to 230°C. The holding time of the heating temperature is preferably 1 minute or longer, more preferably 20 minutes or longer, and preferably 100 minutes or shorter, more preferably 60 minutes or shorter.

[0059]

<Step (D)>

In the step (D), for example, the expandable multi-layered resin particles thus impregnated with the blowing agent and heated by the step (C) are released from the closed vessel into an atmosphere having a pressure lower than the internal pressure of the closed vessel, and at least the core layer can be foamed into a foamed core layer to produce expanded beads.

Specifically, while the internal pressure of the closed vessel is kept at a pressure equal to or higher than the vapor pressure of the blowing agent, one end beneath the water surface in the closed vessel is opened so that the expandable multi-layered resin particles impregnated with the blowing agent are released together with the dispersing medium from the closed vessel into an atmosphere having a pressure lower than the internal pressure of the closed vessel, usually under atmospheric pressure, and at least the core layer of the expandable multi-layered resin particles can be foamed into a foamed core layer to prepare expanded beads in a multi-layered structure having a foamed core layer and a cover layer covering the foamed core layer. Alternatively, the expandable multi-layered resin particles which have undergone the step (C) may be cooled and taken out, and the resulting expandable multi-layered resin particles can be expanded by heating with a heating medium such as hot air or steam to prepare expanded beads.

[0060]

In the step (D), the internal temperature of the closed vessel at the time of expansion is usually preferably from 110°C to 170°C. The internal pressure of the closed vessel is preferably 0.5 MPa (G) or higher and 5 MPa (G) or lower.

[0061]

The aforementioned steps (B) to (D) are preferably performed as a series of steps in a single closed vessel, and may be performed as separate steps in such a way that the multi-layered resin particles, etc. may be taken out in each step, added into a closed vessel again, and subjected to the next step.

[0062]

Expanded beads having a crystal structure where a melting peak intrinsic for a resin (resin-intrinsic peak) and at least one melting peak on the higher temperature side therefrom (high-temperature peak) appear in a first time DSC curve obtained by the differential scanning calorimetry (DSC) of the expanded beads are obtained, for example, as follows.

A one-stage holding step is performed in which the resin particles are held at a temperature equal to or higher than (the melting point of the polypropylene resin (C) - 20°C) and lower than (the end temperature of melting of the polypropylene resin (C)) for a sufficient time, preferably approximately 10 to 60 minutes, at the time of heating in the expanded beads production process. Then, the temperature is adjusted to from (the melting point of the polypropylene resin (C) - 15°C) to (the end temperature of melting of the polypropylene resin (C) + 10°C). If necessary, a two-stage holding step is performed in which the resin particles are further held at that temperature for a sufficient time, preferably approximately 10 to 60 minutes. Subsequently, the expandable resin particles containing the blowing agent can be released from the closed vessel to under lower pressure for expansion to obtain expanded beads having the aforementioned crystal structure. The expansion is preferably performed at a temperature equal to or higher than (the melting point of the polypropylene resin (C) - 10°C) in the closed vessel, and more preferably performed at a temperature equal to or higher than (the melting point of the polypropylene resin (C)) and equal to or lower than (the melting point of the polypropylene resin (C) + 20°C). [0063]

The expanded beads obtained as described above may be heated with steam or the like (two-stage expansion) after elevation of the internal pressure by pressurization treatment with air, to prepare expanded beads having a higher expansion ratio (lower apparent density). [0064]

[Expanded polypropylene resin beads molded article]

An expanded polypropylene resin beads molded article obtained using the expanded polypropylene resin bead of the present invention (hereinafter, also simply referred to as the expanded polypropylene resin beads molded article or the expanded beads molded article) can be obtained by the in-mold molding of the expanded polypropylene resin bead of the present invention. [0065]

The in-mold molding method can be performed by filling expanded beads into a mold for molding and molding the expanded beads by heating using a heating medium such as steam. Specifically, the expanded beads are filled into a mold for molding. Then, a heating medium such as steam is introduced into a mold for molding so that the expanded beads can be expanded by heating while

fusion bonded to each other to obtain an expanded beads molded article shaped in the shape of molding space. The in-mold molding according to the present invention is preferably performed by a pressure molding method in which the expanded beads are pressurized with a pressurized gas such as air to increase the pressure within the cells of the expanded beads, and after adjustment of the pressure within the expanded beads to a pressure higher by 0.01 to 0.3 MPa than atmospheric pressure, the expanded beads are filled into a mold for molding under atmospheric pressure or reduced pressure and subsequently fusion bonded by heating a heating medium, such as steam, fed into the mold (for example, JP S51-22951 A). Alternatively, the molding may be performed by a compression filling molding method in which the expanded beads are filled into a mold for molding pressurized to a pressure equal to or higher than atmospheric pressure with a compressed gas while the expanded beads are pressurized to that pressure or higher, and then heated with a heating medium, such as steam, fed into the cavity so that the expanded beads are heat fusion bonded (JP H4-46217 A). In addition, the molding may be performed by an ambient pressure filling molding method in which the expanded beads with high secondary expansion force obtained under special conditions are filled within a cavity of a mold for molding under atmospheric pressure or reduced pressure, and subsequently heated with a fed heating medium, such as steam, for the heat fusion bonding of the expanded beads (JP H6-49795 A), or a combined method of the aforementioned methods (JP H6-22919 A) or the like.

[0066]

<Density>

The density of the expanded polypropylene resin beads molded article is preferably 10 kg/m³ or larger, more preferably 15 kg/m³ or larger, further preferably 20 kg/m³ or larger, and preferably 150 kg/m³ or smaller, more preferably 100 kg/m³ or smaller, further preferably 50 kg/m³ or smaller, particularly preferably 35 kg/m³ or smaller, from the viewpoint of achieving both mechanical strength and lightness in weight in a well-balanced manner.

The density of the expanded beads molded article is calculated by dividing the mass (g) of the expanded beads molded article by a volume (L) determined from the outside dimension of the molded article, followed by unit conversion. If the volume is not easy to determine from the outside dimension of the molded

article, the volume of the molded article can be determined by a submersion method.

[0067]

<50% compression stress>

The 50% compression stress of the expanded polypropylene resin beads molded article is preferably 50 kPa or larger, more preferably 100 kPa or larger, further preferably 150 kPa or larger, and preferably 500 kPa or smaller, more preferably 400 kPa or smaller, further preferably 300 kPa or smaller, from the viewpoint of rigidity.

The 50% compression stress of the expanded beads molded article is measured in accordance with JIS K 6767: 1999.

EXAMPLES

[0068]

Hereinafter, the present invention will be described in detail with reference to Examples. However, the present invention is not limited by these examples by any means.

[0069]

Resins, expanded beads and expanded beads molded articles used in Examples and Comparative Examples were measured or evaluated as described below. The physical properties of the expanded beads were measured using expanded beads left standing for 24 hours under conditions of 50% relative humidity, 23°C and 1 atm and thereby conditioned. The physical properties of the expanded beads molded articles were measured and evaluated using molded articles conditioned by leaving standing expanded beads molded articles after mold release for 12 hours under conditions of 50% relative humidity, 80°C and 1 atm.

[0070]

[Measurement methods]

<Polypropylene resin>

(Monomer component content)

The monomer component content of a polypropylene resin was determined by a known method for determining the content by an IR spectrum. Specifically, the content was determined by the method described in Polymer Analysis Handbook (edited by Research Committee of Polymer Analysis, The Japan

Society for Analytical Chemistry, published in January 1995, publisher: Kinokuniya Co., Ltd., page numbers and section titles: 615-616 "II.2.3 2.3.4 Propylene/Ethylene Copolymer", 618-619 "II.2.3 2.3.5 Propylene/Butene Copolymer"), i.e., a method of performing quantification from the relationship between the absorbance values of ethylene and butene corrected with predetermined coefficients and the thickness of a test piece in a film-like form, etc. More specifically, the polypropylene resin was first molded in a film-like form by hot pressing in an environment of 180°C to prepare a plurality of test pieces differing in thickness. Subsequently, the IR spectrum of each test piece was measured to read ethylene-derived absorbance at 722 cm⁻¹ and 733 cm⁻¹ (A₇₂₂ and A₇₃₃) and butene-derived absorbance at 766 cm⁻¹ (A₇₆₆). Subsequently, the content of the ethylene component in the polypropylene resin was calculated as to each test piece according to the expressions (1) to (3) given below. The respective ethylene component contents obtained as to the test pieces were arithmetically averaged, and the resulting value was regarded as the ethylene component content (unit: % by mass) of the polypropylene resin.

$$(K'_{733})_c = 1 / 0.96\{(K'_{733})_a - 0.268(K'_{722})_a\} \dots (1)$$

$$(K'_{722})_c = 1 / 0.96\{(K'_{722})_a - 0.268(K'_{733})_a\} \dots (2)$$

$$\text{Ethylene component content (\%)} = 0.575\{(K'_{722})_c + (K'_{733})_c\} \dots (3)$$

In the expressions (1) to (3), K'a represents an apparent absorption coefficient at each wave number (K'a = A / ρt), K'c represents an absorption coefficient after correction, A represents absorbance, ρ represents the density of the resin (unit: g/cm³), and t represents the thickness of the test piece in a film-like form (unit: cm).

Also, the content of the butene component in the polypropylene resin was calculated as to each test piece according to the expression (4) given below. The respective butene component contents obtained as to the test pieces were arithmetically averaged, and the resulting value was regarded as the butene component content (%) of the polypropylene resin.

$$\text{Butene component content (\%)} = 12.3(A_{766} / L) \dots (4)$$

In the expression (4), A represents absorbance, and L represents the thickness (mm) of the test piece in a film-like form.

[0071]

(DSC characteristics of polypropylene resin (S))

A peak shape, a peak top temperature T_{msl} of a melting peak on the lower temperature side and a peak top temperature T_{msh} of a melting peak on the higher temperature side of the polypropylene resin (S) in the second time DSC curve of the polypropylene resin (S) were determined as follows: a DSC curve was obtained in accordance with JIS K 7121: 1987 by adopting "(2) the case of measuring a fusion temperature after performing a certain heat treatment" for the conditioning of a test piece, and heating a conditioned test piece from 30°C to 200°C at a heating rate of 10°C/min. Specifically, approximately 3 mg of the resin conditioned at 23°C for 24 hours or longer in a 50% RH atmosphere was used as a test piece, and this test piece was heated from 30°C to 200°C at a heating rate of 10°C/min, subsequently cooled from 200°C to 30°C at a cooling rate of 10°C/min, and heated again from 30°C to 200°C at a heating rate of 10°C/min using a heat flux differential scanning calorimeter (manufactured by Shimadzu Corp., model: DSC-60A) to obtain a DSC curve in which the shape of melting peaks was then observed. In this context, a double shape as a peak shape means that two melting peaks having the peak top temperatures (melting points) of peaks different from each other appear and both the heat of fusions of these two melting peaks are 10 J/g or higher. The heat of fusions are values determined by a method mentioned later. Since PP2 had a single peak shape in which only one melting peak appeared, the peak top temperature of this melting peak is shown only in the column of the peak top temperature of the melting peak on the lower temperature side. The second time DSC curve of PP1 is shown in FIG. 1. The second time DSC curve of PP2 is shown in FIG. 3.

[0072]

(Heat of fusions ΔH of polypropylene resin (S))

The heat of fusions of the polypropylene resin (S) were determined as follows: a point at a temperature of 80°C on a DSC curve was defined as α , and a point corresponding to an end temperature of melting on the DSC curve was defined as β (see FIG. 1). A straight line parallel to the ordinate of the graph was drawn from point γ , on the DSC curve, corresponding to the valley between melting peak P_l on the lower temperature side and melting peak P_h on the higher temperature side, and a point intersecting with a straight line (α - β) which connected the point α and the point β was defined as δ . An area (A) of the melting peak P_l on the lower temperature side was regarded as heat of fusion ΔH_l of the melting peak P_l on the lower temperature side, and determined as the area

of a portion surrounded by the DSC curve depicting the melting peak P_l on the lower temperature side, a line segment ($\alpha\delta$) and a line segment ($\gamma\delta$). An area (B) of the melting peak P_h on the higher temperature side was regarded as heat of fusion ΔH_h of the melting peak P_h on the higher temperature side, and determined as the area of a portion surrounded by the DSC curve depicting the melting peak P_h on the higher temperature side, a line segment ($\delta\beta$) and the line segment ($\gamma\delta$).

Total heat of fusion ΔH_t was defined as the total sum [$A + B$, i.e., $\Delta H_l + \Delta H_h$] of the area (A) of the melting peak P_l on the lower temperature side and the area (B) of the melting peak P_h on the higher temperature side, and in FIG. 1, was determined as the area of a portion surrounded by the straight line ($\alpha\beta$) and the DSC curve at a zone from the point α to the point β .

Since PP2 had a single peak shape in which only one melting peak appeared, the heat of fusion of this melting peak is shown in the column of the heat of fusion of the melting peak on the lower temperature side.

[0073]

(Melting point of polypropylene resin (C))

A melting point T_{mc} of the polypropylene resin (C) was determined in accordance with JIS K 7121: 1987 by adopting "(2) the case of measuring a fusion temperature after performing a certain heat treatment" for the conditioning of a test piece. Specifically, approximately 3 mg of the resin conditioned at 23°C for 24 hours or longer in a 50% RH atmosphere was used as a test piece, and this test piece was heated from 30°C to 200°C at a heating rate of 10°C/min, subsequently cooled from 200°C to 30°C at a cooling rate of 10°C/min, and heated again from 30°C to 200°C at a heating rate of 10°C/min using a heat flux differential scanning calorimeter (manufactured by Shimadzu Corp., model: DSC-60A) to obtain a DSC curve. T_{mc} was determined as the peak top temperature of a melting peak associated with the melting of the resin on the DSC curve.

[0074]

(MFR)

MFR of a polypropylene resin was measured under conditions involving a temperature of 230°C and a load of 2.16 kg in accordance with JIS K 7210-1: 2014.

[0075]

(Flexural modulus)

The flexural modulus of a polypropylene resin was determined in accordance with JIS K 7171: 2016 by preparing a 4 mm thick sheet by heat pressing at 230°C, and cutting the sheet into 80 mm long × 10 mm wide × 4 mm thick (standard test piece). Radius R1 of an indenter and radius R2 of a supporting table were both set to 5 mm, the distance between supporting points was set to 64 mm, and the test rate was set to 2 mm/min.

[0076]

<Expanded beads>

(Bulk density)

The bulk density of expanded beads was determined by taking out expanded beads from a group of conditioned expanded beads at random, placing the expanded beads in a 1-liter capacity graduated cylinder such that many expanded beads were contained in a spontaneously deposited state up to the scale marking of 1 L, dividing mass W1 [g] of the contained expanded beads by volume V1 (1 [L]) of the contents (W1 / V1), and converting the unit to [kg/m³].

[0077]

(Heat of fusion of high-temperature peak)

One expanded bead was collected from a group of conditioned expanded beads. This expanded bead was used as a test piece, and a DSC curve was obtained when the test piece was heated from 23°C to 200°C at a heating rate of 10°C/min using a differential scanning calorimeter (specifically, manufactured by Shimadzu Corp., model: DSC-60A). FIG. 2 shows one example of the DSC curve. The DSC curve shown in FIG. 2 has resin-intrinsic peak P₁ and high-temperature peak P₂ on the higher temperature side therefrom. Straight line L1 was obtained by connecting point α at a temperature of 80°C on the DSC curve with point β at an end temperature of melting T of the expanded bead. Next, straight line L2 parallel to the ordinate of the graph was drawn from point γ, on the DSC curve, corresponding to the valley between the resin-intrinsic peak P₁ and the high-temperature peak P₂, and a point at which the straight line L1 and the straight line L2 intersected with each other was defined as δ. An area (2) of the high-temperature peak P₂ of the expanded bead was regarded as heat of fusion ΔH2 of the high-temperature peak P₂, and determined as the area of a portion surrounded by the DSC curve depicting the high-temperature peak P₂, a line segment (δ-β) and a line segment (γ-δ). The aforementioned measurement was

performed as to five expanded beads, and a value obtained by arithmetic averaging is shown in Tables 3 and 4.

[0078]

<Expanded beads molded article>

(Molded article density)

The density of an expanded beads molded article was determined as a value obtained by removing a skin layer of molding from the expanded beads molded article, cutting the resultant into three test pieces at random in a 25 mm long $\times$ 25 mm wide $\times$ 100 mm thick cuboid-like form, measuring the mass and volume of each test piece, dividing the mass by the volume, followed by unit conversion to calculate the densities of the three test pieces, and arithmetically averaging the densities.

[0079]

(50% compression stress)

The 50% compression stress of an expanded beads molded article was determined as a 50% compression stress [kPa] calculated by removing a skin layer from the expanded beads molded article, cutting the resultant into a test piece in a 50 mm long $\times$ 50 mm wide $\times$ 25 mm thick cuboid-like form, determining a load at 50% strain when this test piece was compressed at a rate of 10 mm/min using RTF-1350 manufactured by A&D Co., Ltd. in accordance with JIS K 6767: 1999, and dividing this load by the pressure reception area of the test piece.

[0080]

[Evaluation methods]

<Molding pressure range which enables molding (moldability)>

The moldability of expanded beads was evaluated as follows: expanded beads molded articles were prepared at molding pressures (steam pressures) varying by 0.01 MPa (G) in <Preparation of expanded beads molded article> mentioned later. Molding pressures at which the expanded beads molded article was given "A" in the evaluation of all of fusion bonding properties, appearance, and recovery properties given below were regarded as a molding pressure range which enabled molding. The number of such molding pressures (the number of molding pressures at which the expanded beads molded article was given "A" in the evaluation of all the items) is also shown in Tables 3 and 4. Since a molding temperature is adjusted by a molding pressure, a wide range from the lower limit

value to the upper limit value of the molding pressure which enables molding means a wide mold heating temperature range which enables molding.

(Fusion bonding properties)

The fusion bonding properties of an expanded beads molded article was evaluated by the following method: the expanded beads molded article was bent and ruptured. The number (C1) of expanded beads present on the ruptured cross section and the number (C2) of ruptured expanded beads were determined. The ratio of the ruptured expanded beads to the aforementioned expanded beads ($C2 / C1 \times 100$) was calculated as a material destruction rate. The measurement was performed five times using different test pieces to determine their respective material destruction rates, which were then arithmetically averaged. The fusion bonding properties were evaluated according to the following criteria.

A: Material destruction rate of 90% or more

B: Material destruction rate of 20% or more and less than 90%

C: Material destruction rate of less than 20%

(Appearance (degree of voids))

A 100 mm × 100 mm rectangle was drawn in the central part of an expanded beads molded article, and lines were drawn on diagonals from the corners of the rectangular area. The number of voids having a size of 1 mm × 1 mm or larger on the lines was counted. The surface appearance of the expanded beads molded article was evaluated according to the following criteria.

A: The number of voids is less than 3

B: The number of voids is 3 or more and less than 5

C: The number of voids is 5 or more

(Recovery properties)

The respective thicknesses of the central portion and four corner portions of the obtained expanded beads molded article were measured, and the ratio of the thickness of the central portion to the thickness of the thickest portion among the four corner portions was calculated. The recovery properties were evaluated according to the following criteria.

A: The thickness ratio is 95% or more

B: The thickness ratio is 90% or more and less than 95%

C: The thickness ratio is less than 90%

[0081]

<Molding pressure range which attains favorable mold release properties (mold release properties)>

Mold release properties were evaluated according to the following criteria in the molding pressure range which enabled molding in the aforementioned evaluation of <Molding pressure range which enables molding (moldability)>. Molding pressures at which the test sample was given "A" in the evaluation were regarded as molding pressures which attained favorable mold release properties. The number of such molding pressures (the number of molding pressures at which the test sample was given "A" in the evaluation) is also shown in the tables. A wide range from the lower limit value to the upper limit value of the molding pressure which attains favorable mold release properties means a wide mold heating temperature range which attains favorable mold release properties.

A: The sample can be molded without the use of a mold release assist such as a mold release pin or mold release air

B: The sample cannot be molded without the use of a mold release assist such as a mold release pin or mold release air

[0082]

[Raw materials]

Tables 1 and 2 show the polypropylene resins (S) and the polypropylene resins (C) used in Examples and Comparative Examples. In the tables, PP1 denotes a propylene copolymer containing ethylene, propylene, and butene manufactured by The Polyolefin Company (Singapore) Pte Ltd. (TPC) under the grade name of FL7540L.

In the tables, PP5 denotes a mixed resin of an ethylene-propylene random copolymer (ethylene: 3.1% by mass, melting point: 142°C) and an ethylene-propylene random copolymer (ethylene: 1.4% by mass, melting point: 153°C) (mass ratio: 50% by mass:50% by mass based on 100% by mass in total of these resins). PP6 denotes a mixed resin of an ethylene-propylene random copolymer (ethylene: 4.2% by mass, melting point: 134°C) and linear low-density polyethylene (density: 0.91 g/cm³, melting point: 110°C) (mass ratio: ethylene-propylene random copolymer:linear low-density polyethylene = 67% by mass:33% by mass based on 100% by mass in total of these resins).

[0083]

Table 1

Symbol	Monomer component		Second time DSC characteristics								MFR (g/10 min)
	Monomer component content (% by mass)	Butene component content/ethylene component content ratio	Peak shape	Peak top temperature of melting peak on lower temperature side Tmsl (°C)	Heat of fusion of melting peak on lower temperature side ΔHl (J/g)	Peak top temperature of melting peak on higher temperature side Tmsh (°C)	heat of fusion of melting peak on higher temperature side ΔHh (J/g)	Total heat of fusion ΔHt (J/g)	Tmsh-Tmsl (°C)	ΔHh/ΔHt	
pp1	Ethylene: 4.1% by mass Butene: 9.7% by mass	2.4	Double	128	39.1	142	33.2	72.3	14	0.46	7
pp2	Ethylene: 3.0% by mass Butene: 3.8% by mass	1.3	Single	135	63.5	-	-	63.5	-	-	5
pp3	Ethylene: 3.8% by mass Butene: 4.5% by mass	1.2	Double	122	44.7	134	11.6	56.3	12	0.21	6
pp4	Ethylene: 4.5% by mass	-	Double	117	34.8	125	20.8	55.6	8	0.37	7
pp5	-	-	Single	150	72.8	-	-	72.8	-	-	-
pp6	-	-	Double	110	15.0	134	31.4	46.4	24	0.68	-

[0084]

Table 2

Symbol	Material	Comonomer	Flexural modulus (MPa)	Melting point T _{mc} (°C)	MFR (g/10 min)
PP7	Ethylene-propylene random copolymer	Ethylene: 2.4% by mass	1080	147	9
PP8	Ethylene-propylene random copolymer	Ethylene: 3.1% by mass	980	142	8
PP9	Ethylene-propylene random copolymer	Ethylene: 3.7% by mass	880	138	7
PP10	Homopolypropylene	-	1650	164	9
PP11	Ethylene-propylene random copolymer	Ethylene: 1.4% by mass	1470	153	7

[0085]

Examples 1 to 5 and Comparative Examples 1 to 9

<Preparation of expanded beads>

The polypropylene resin (C) of the type shown in Table 3 or 4 was used and melt kneaded at the highest set temperature of 245°C in an extruder for core layer formation to obtain a core layer-forming melt kneaded resin material. The polypropylene resin (S) of the type shown in Table 3 or 4 was used and melt kneaded at the highest set temperature of 245°C in an extruder for cover layer formation to obtain a cover layer-forming melt kneaded resin material. Subsequently, the melt kneaded resin materials from the extruder for core layer formation and the extruder for cover layer formation, respectively, were extruded from the tip of a coextrusion die. In this respect, these melt kneaded resin materials were combined within the die to form a core-sheath composite consisting of a core layer in a non-foamed state and a cover layer in a non-foamed state covering the outer surface of the core layer. The composite was extruded in a strand-like form from small holes of a nozzle annexed in the tip of the extruder. The material in a strand-like form was cooled in water while taken

over, and then cut in a pelletizer such that the mass was approximately 1.0 mg. In this way, multi-layered resin particles each consisting of a core layer and a cover layer covering the core layer was obtained. The mass ratio between the core layer and the cover layer in the multi-layered resin particles was set to core layer:cover layer = 95:5 (i.e., the mass ratio of the cover layer was 5%). In the production of the multi-layered resin particles, zinc borate as a cell controlling agent was fed to the extruder for core layer formation so that the polypropylene resin contained 500 ppm by mass of zinc borate.

[0086]

(One-stage expansion step)

A 5 L closed vessel was charged with 1 kg of the multi-layered resin particles together with 3 L of water as a dispersing medium. Further, 0.3 parts by mass of kaolin as a dispersant, 0.0001 parts by mass of aluminum sulfate as a dispersion synergist, and 0.004 parts by mass of a surfactant (sodium alkylbenzenesulfonate) based on 100 parts by mass of the multi-layered resin particles were added into the closed vessel. Carbon dioxide was added as a blowing agent into the closed vessel. Then, the closed vessel was hermetically sealed, and the contents within the closed vessel were heated to the expansion temperature shown in Table 3 or 4 with stirring. In this respect, the internal pressure of the vessel (i.e., the impregnation pressure or the carbon dioxide pressure) was as shown in Table 3 or 4. After holding at the same temperature as above for 15 minutes, the contents in the vessel were released to under atmospheric pressure to obtain expanded beads. The resulting expanded beads were dried at 23°C for 24 hours. In this way, expanded beads having the bulk ratio shown in Table 3 or 4 were obtained.

[0087]

(Two-stage expansion step)

Subsequently, the expanded beads were placed in a pressure-resistant vessel (specifically, a metal drum), and air was put under pressure into the pressure-resistant vessel so that the internal pressure of the vessel was elevated while the pressure within the cells of the expanded beads was elevated by the impregnation of the cells with air. Subsequently, steam was fed to the expanded beads taken out of the pressure-resistant vessel (one-stage expanded beads) such that the internal pressure of the pressure-resistant vessel (i.e., the drum pressure) was the pressure shown in Table 3 or 4. The resulting expanded

beads were heated under atmospheric pressure. The pressure within the cells (i.e., the internal pressure) in the one-stage expanded beads taken out of the pressure-resistant vessel was the value shown in Table 3 or 4. In this way, the apparent density of the one-stage expanded beads was lowered to obtain expanded beads having the bulk ratio shown in Table 3 or 4 (two-stage expanded beads).

[0088]

<Preparation of expanded beads molded article>

Expanded beads dried at 23°C for 24 hours were used in the production of an expanded beads molded article. First, an internal pressure of 0.25 MPa (G) was applied to the expanded beads using compressed air, and the expanded beads were filled into a vertical molding machine having a 300 mm long × 250 mm wide × 60 mm thick cavity, with the amount of cracking adjusted to 20% (i.e., 12 mm), followed by mold clamping. Steam was fed for 5 seconds from both sides of the mold for preliminary heating to perform an exhaust step. The vertical molding machine is a molding machine in which the direction of opening of a mold is a vertical direction (height direction). Then, steam was fed from one side of the mold until the pressure reached a pressure lower by 0.08 MPa (G) than the predetermined molding pressure, while heating was performed. Subsequently, steam was fed from the other side of the mold until the pressure reached a pressure lower by 0.04 MPa (G) than the molding pressure, while heating was performed. Then, heating (i.e., main heating) was performed until the pressure reached the predetermined molding pressure. After the completion of heating, the pressure was released, and cooling in water was performed until the surface pressure ascribable to expansion force of the molded article became 0.04 MPa (G), followed by mold release to obtain an expanded beads molded article.

[0089]

Table 3

		Example				
			1	2	3	5
			PP1	PP1	PP1	PP1
Multi-layered resin particles	Cover layer	Resin species (polypropylene resin (S))	-			
		Peak top temperature Tmsl of melting peak on lower temperature side Tmsl	128	128	128	128
	Core layer	Peak top temperature Tmsh of melting peak on higher temperature side Tmsh	142	142	142	142
		Resin species (polypropylene resin (C))	PP7	PP7	PP7	PP9
		Melting point Tmc	147	147	147	138
One-stage expansion step		Tmc-Tmsh	5	5	5	-4
		Tmc-Tmsl	19	19	19	10
		Expansion temperature	154.5	153.4	154.5	146.5
		Carbon dioxide pressure	2.4	2.7	2.4	2.7
		Bulk ratio	16.3	16.0	16.3	15.8
Two-stage expansion step		Internal pressure	4.9	5.3	5.4	5.1
		Drum pressure	0.05	0.05	0.07	0.05
		Bulk ratio	35.5	33.8	49.7	34.0
Expanded beads		Bulk density	25.4	26.6	18.1	26.5
		Heat of fusion of high-temperature peak ΔH2	13.0	16.1	13.2	13.6
		Molding pressure range which enables molding	0.28-0.32	0.30-0.34	0.28-0.32	0.24-0.28
Evaluation		Evaluation: the number of molding pressures	5	5	5	5
		Molding pressure range which attains favorable mold release properties	0.28-0.32	0.30-0.34	0.28-0.32	0.24-0.28
		Evaluation: the number of molding pressures	5	5	5	5
Molded article		Molding pressure	0.28	0.30	0.28	0.28
		Molded article density	30.1	34.8	20.5	32.6
		50% compression stress	210	266	163	253

[0091]

As is evident from Table 3, the expanded beads of the present invention have a wide molding pressure range which enables molding, and has favorable mold release properties in the entire molding pressure range. If an expanded beads molded article is unintentionally affixed to a mold upon mold release, a mold release assist such as a mold release pin or mold release air is generally used. The expanded beads of the present invention eliminate the need of such a mold release assist means and can therefore improve production efficiency.

As is evident from Table 4, it was difficult to achieve both mold release properties and moldability in Comparative Example 1, Comparative Example 7 and Comparative Example 9 in which the polypropylene resin (S) had a single peak without having a double peak, and did not satisfy the aforementioned requirement (1). As is evident from the comparison between Comparative Example 1 and Comparative Example 9, expanded beads having a low bulk density were more likely to have poor mold release properties, in particular.

Mold release properties were poor in Comparative Example 2, Comparative Example 3 and Comparative Example 8 in which the peak top temperature of the melting peak on the higher temperature side of the polypropylene resin (S) was lower than 138°C and did not satisfy the aforementioned requirement (3).

Mold release properties were also poor in Comparative Example 5 in which the difference $[T_{mc} - T_{msh}]$ between the melting point T_{mc} of the polypropylene resin (C) and the peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) was more than 15°C and did not satisfy the aforementioned requirement (4).

Mold release properties were markedly poor in Comparative Example 4 in which the peak top temperature of the melting peak on the higher temperature side of the polypropylene resin (S) was lower than 138°C and did not satisfy the aforementioned requirement (3), and the difference $[T_{mc} - T_{msh}]$ between the melting point T_{mc} of the polypropylene resin (C) and the peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) was more than 15°C and did not satisfy the aforementioned requirement (4).

INDUSTRIAL APPLICABILITY

[0092]

The expanded bead of the present invention has a wide molding pressure range which enables molding, and has excellent mold release properties and as such, is useful because the excellent mold release properties are exerted using even a general-purpose apparatus, not a special apparatus.

CLAIMS

1. An expanded polypropylene resin bead comprising a foamed core layer constituted of a polypropylene resin (C) and a cover layer constituted of a polypropylene resin (S), wherein
the polypropylene resin (C) has a melting point T_{mc} of 125°C or higher and 170°C or lower, and
the expanded polypropylene resin bead satisfies the following (1) to (4):
 - (1) the polypropylene resin (S) has a melting peak on the lower temperature side and a melting peak on the higher temperature side in a second time DSC curve obtained by heat flux differential scanning calorimetry when the resin is heated from 30°C to 200°C at a heating rate of 10°C/min, subsequently cooled from 200°C to 30°C at a cooling rate of 10°C/min, and heated again at a heating rate of 10°C/min;
 - (2) a peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is lower than the melting point T_{mc} of the polypropylene resin (C);
 - (3) a peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) is 138°C or higher; and
 - (4) a difference [$T_{mc} - T_{msh}$] between the melting point T_{mc} of the polypropylene resin (C) and the peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) is -10°C or more and 15°C or less.
2. The expanded polypropylene resin bead according to claim 1, wherein the peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is 125°C or higher and 135°C or lower.
3. The expanded polypropylene resin bead according to claim 1 or 2, wherein a difference [$T_{mc} - T_{msl}$] between the melting point T_{mc} of the polypropylene resin (C) and the peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is more than 0°C and 25°C or less.
4. The expanded polypropylene resin bead according to any one of claims 1 to 3, wherein a ratio [$\Delta H_h/\Delta H_t$] of a heat of fusion (ΔH_h) of the melting peak on the

higher temperature side of the polypropylene resin (S) to a total heat of fusion (ΔH_t) of the polypropylene resin (S) is 0.35 or more and 0.80 or less.

5. The expanded polypropylene resin bead according to any one of claims 1 to 4, wherein a difference $[T_{msh} - T_{msl}]$ between the peak top temperature T_{msh} of the melting peak on the higher temperature side and the peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is 10°C or more and 20°C or less.

6. The expanded polypropylene resin bead according to any one of claims 1 to 5, wherein the melting point T_{mc} of the polypropylene resin (C) is 130°C or higher and 150°C or lower.

7. The expanded polypropylene resin bead according to any one of claims 1 to 6, wherein the polypropylene resin (S) is a propylene copolymer that is composed mainly of a propylene component and comprises an ethylene component and a butene component.

8. The expanded polypropylene resin bead according to any one of claims 1 to 7, wherein the expanded polypropylene resin bead has a bulk density of 10 kg/m³ or larger and 30 kg/m³ or smaller.

9. A method for producing an expanded polypropylene resin bead, comprising the steps of:

performing granulation into multi-layered resin particles each comprising a core layer constituted of a polypropylene resin (C) and a cover layer constituted of a polypropylene resin (S) and covering the core layer;

dispersing the multi-layered resin particles in a dispersing medium in a closed vessel;

impregnating the multi-layered resin particles dispersed in the dispersing medium with a blowing agent; and

expanding the multi-layered resin particles containing the blowing agent to produce expanded beads, wherein

the polypropylene resin (C) has a melting point T_{mc} of 125°C or higher and 170°C or lower, and

the expanded polypropylene resin bead satisfies the following (1) to (4):

(1) the polypropylene resin (S) has a melting peak on the lower temperature side and a melting peak on the higher temperature side in a second time DSC curve obtained by heat flux differential scanning calorimetry when the resin is heated from 30°C to 200°C at a heating rate of 10°C/min, subsequently cooled from 200°C to 30°C at a cooling rate of 10°C/min, and heated again at a heating rate of 10°C/min;

(2) a peak top temperature T_{msl} of the melting peak on the lower temperature side of the polypropylene resin (S) is lower than the melting point T_{mc} of the polypropylene resin (C);

(3) a peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) is 138°C or higher; and

(4) a difference [$T_{mc} - T_{msh}$] between the melting point T_{mc} of the polypropylene resin (C) and the peak top temperature T_{msh} of the melting peak on the higher temperature side of the polypropylene resin (S) is -10°C or more and 15°C or less.