[3] The catalyst according to [1] or [2], wherein the alkali metal element comprises cesium.

[4] The catalyst of any one of [1] to [3], wherein the first metal element comprises zirconium.

[5] The catalyst according to any one of [1] to [4], which is a catalyst for producing an unsaturated carboxylic acid and/or an unsaturated carboxylic ester.

[6] A method for producing an unsaturated carboxylic acid and/or an unsaturated carboxylic acid ester by reacting a carboxylic acid and/or a carboxylic acid ester with formaldehyde in the presence of the catalyst according to any one of [1] to [5].

[7] A method for producing a catalyst comprising (i) a compound comprising at least one first metal element selected from boron, magnesium, zirconium, and hafnium, and (ii) an alkali metal element the compound and the alkali metal element being supported on a carrier, the method comprising

impregnating the carrier with a solution or dispersion containing an inorganic salt of the first metal element to obtain the first solid, and

impregnating the first solid with a solution or dispersion containing an alkali metal salt to obtain the second solid.

wherein an average particle size of an inorganic salt of the first metal element is 0.4nm or more and 50 nm or less, and

the catalyst satisfies the following formula (2):

1.5×10^{-21} (g/ number) $\leqq X'/(Y' \times Z') \leqq 17.0 \times 10^{-21}$ (g/number) ・・・ formula (2),

in which X' is a molar ratio of the alkali metal element to the at least one first metal element in the catalyst, Y' is a BET specific surface area of the catalyst (m^2/g), and Z' is a number of the silanol groups per unit area (number/nm^2).

[8] The method according to [7], wherein a solvent of the solution or dispersion containing an inorganic salt of the first metal element contains alcohol.

[9] The method according to [7] or [8], wherein the first metal element is zirconium.

[10] The method according to any one of [7] to [9], wherein the alkali metal element is cesium.

Effect of invention

[0008]

Claims

1. A catalyst for producing an unsaturated carboxylic acid and/or an unsaturated carboxylic ester comprising:

(i) a compound comprising at least one first metal element selected from boron, magnesium, zirconium, and hafnium, and

(ii) an alkali metal element,

wherein the compound and the alkali metal element are supported on a carrier having silanol groups,

an average particle size of the compound of the first metal element is 0.4 nm or more and 50 nm or less,

the catalyst satisfies the following formula (1):

1.0×10^{-21} (g/number) $\leqq X / (Y \times Z) < 10.8 \times 10^{-21}$ (g/number) ・・・ formula (1),

in which X is a molar ratio of the alkali metal element to the at least one first metal element in the catalyst, Y is a BET specific surface area of the catalyst (m^2/g), and Z is a number of the silanol groups per unit area (number/nm^2).

2. The catalyst according to claim 1, wherein the molar ratio X of the alkali metal element to the first metal element is 1.3 or more and 6.0 or less.

3. The catalyst according to claim 1 or 2, wherein the alkali metal element comprises cesium.

4. The catalyst of any one of claims 1 to 3, wherein the first metal element comprises zirconium.

5. A method for producing an unsaturated carboxylic acid and/or an unsaturated carboxylic acid ester by reacting a carboxylic acid and a carboxylic acid ester with formaldehyde in the presence of the catalyst according to any one of claims 1 to 4.

6. A method for producing the catalyst for producing an unsaturated carboxylic acid and/or an unsaturated carboxylic ester according to any one of claims 1 to 5 comprising

(i) a compound comprising at least one first metal element selected from boron, magnesium, zirconium, and hafnium, and

(ii) an alkali metal element the compound and the alkali metal element being supported on a carrier, the method comprising

impregnating the carrier with a solution or dispersion containing an inorganic salt of the first metal element to obtain the first solid, and

impregnating the first solid with a solution or dispersion containing an alkali metal salt to obtain the second solid.

wherein an average particle size of an inorganic salt of the first metal element is 0.4 nm or more and 50 nm or less, and

the catalyst satisfies the following formula (2):

1.5×10^{-21} (g/ number) $\leqq X'/(Y' \times Z') \leqq 17.0 \times 10^{-21}$ (g/number) ・・・ formula (2),

in which X' is a molar ratio of the alkali metal element to the at least one first metal element in the catalyst, Y' is a BET specific surface area of the catalyst (m^2/g), and Z' is a number of the silanol groups per unit area (number/nm^2).

7. The method according to claim 6, wherein a solvent of the solution or dispersion containing an inorganic salt of the first metal element contains alcohol.

8. The method according to claim 6 or 7, wherein the first metal element is zirconium.

9. The method according to any one of claims 6 to 8, wherein the alkali metal element is cesium.