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## **Compressive property of hollow glass microsphere/epoxy resin syntactic foam and its fracture mechanism**

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**Abstract:** The hollow glass microspheres were sieved to have different particle sizes, and the syntactic foams by blending hollow glass microspheres with epoxy resin were prepared. The compressive mechanical properties of the syntactic foams were studied by quasi-static compressive tests. In addition, the microscopic structure was observed by SEM. By using the random spatial dispersing method, model of syntactic foams filled with particles having varied particle size were built. And finite element method was utilized to analyze the behavior of the matrix and particles under 1 kPa pressure. The result shows that as the particle diameter of hollow glass microspheres increases from 30 m to 120 m, the compressive strength of syntactic foam does not have significant change. With finite element analysis, it is found that hollow glass microspheres are the main energy loader. The value of von-Mises stress located on the hollow microspheres is higher than that of stress located on the matrix. The maximum stress is located on the inner surface of hollow glass microspheres, and it could also infer that microspheres are fully squeezed before crack from inside out with the SEM observation.

**Keywords:** syntactic foam hollow microsphere compression diameter finite element analysis

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|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|
| e |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |     |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 |

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|--------------------------------|---|--|-------------|---|-----------------------|--------------------------------|----------------------------|-----------------------|-----------------------|-----------------------|---------------------|---|---------------------|
| 43                             | ÿ   | ä  | .           | á?                                      | ? ?                   | c                              | á?                         | ? ?                   | ÿ                     | [J].                  | c                   | ä | , 2004,21(1): 90    |
| 44                             | ü,  | .ä   | .           | "                                       |                       |                                | [J].                       | c                     | ä                     | , 2004,21(2): 76-80   |                     |   |                     |
| 45                             | ,   | .  | -           | M                                       | Iv                    |                                | á                          | í[J].                 | c                     | ä                     | , 2004,21(3): 11-16 |   |                     |
| 46                             | ,   | .  | á?          | ? ?                                     | c oy                  | á?                             | ? ?                        | o [J].                | c                     | ä                     | , 2003,20(6): 67-72 |   |                     |
| 47                             | ,   | ,  | ,           | 糟                                       |                       | h                              | éoy                        | [J].                  | c                     | ä                     | , 2003,20           |   |                     |
| (1): 91-95                     |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 48                             | ,   | ,  | ,           | ü,                                      | .                     | ä                              | á                          | ' z                   | oy                    | [J].                  | c                   | ä | , 2003,20(2): 19-24 |
| 49                             | Cö  | ,  | ,           | ä .C                                    | L x !                 | oy                             | [J].                       | c                     | ä                     | , 2002,19(6): 8-12    |                     |   |                     |
| 50                             | ,   | Cö   | C .         | c c x ?? ? ?                            | oy                    | oy                             | [J].                       | o [J].                | c                     | ä                     | , 2002,19(5): 108-  |   |                     |
| 113                            |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 51                             | ,   | .  | Ö           | ,                                       | ,                     | é                              | L ü                        | o [J].                | c                     | ä                     | , 2002,19(5):       |   |                     |
| 114-117                        |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 52                             | ,   | ,  | ,           | .PP/GMT                                 |                       | ψ                              | [J].                       | c                     | ä                     | , 2002,19(1): 17-21   |                     |   |                     |
| 53                             | .   | v ? ? ?                                    | .           | [J].                                    | c                     | ä                              | , 2001,18(1): 93-96        |                       |                       |                       |                     |   |                     |
| 54                             | ?? ? ? ? ? ? ? ?                            |  |             |   | [J].                  | c                              | ä                          | , 2001,18(4): 108-114 |                       |                       |                     |   |                     |
| 55                             | Cö , ?                                      | ,  | .           | ! ? c c x oy                            |                       | í[J].                          | c                          | ä                     | , 2001,18(1): 115-119 |                       |                     |   |                     |
| 56                             | .? ? ?                                      |  |             | Ö? ? ? ? ? ? ? ? ? ? ? ?                |                       | 巴                              | w [J].                     | c                     | ä                     | , 2001,18(3): 133-139 |                     |   |                     |
| 57                             | h ,   | ,  | ?           | .? ? ? ? ? ? ? SiC <sub>p</sub> /6061Al | c                     | í ü                            | [J].                       | c                     | ä                     | , 2008,25(4): 119     |                     |   |                     |
| -125                           |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 58                             | ,   | ,  | .           | q                                       | c                     |                                | [J].                       | c                     | ä                     | , 2008,25(4): 181-186 |                     |   |                     |
| 59                             | ,   | .  | á?          | ? ? c                                   |                       | o [J].                         | c                          | ä                     | , 2008,25(4): 198-204 |                       |                     |   |                     |
| 60                             | Al <sub>2</sub> O <sub>3</sub> /Cu          | é ? ? ? ?                                  | ÿ           | [J]. c                                  | á , 1998,15(1): 78-82 | Al <sub>2</sub> O <sub>3</sub> |                            |                       |                       |                       |                     |   |                     |
| c ä , 1999,16(1): 8-13         | ,   | ,  | ,           | á , -                                   | .SiC                  | c é                            | oy                         | o [J].                |                       |                       |                     |   |                     |
| 61                             | ,   | .  | á           | c M                                     | e Ö? ? ?              |                                | [J].                       | c                     | ä                     | , 2000,17(2):         |                     |   |                     |
| 20-24                          |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 63                             | Cö , ?                                      | ,  | .           | c o !                                   | oy                    | [J].                           | c                          | ä                     | , 2000,17(2): 114-118 |                       |                     |   |                     |
| 64                             | ,   | ¥  | .           | q x 帧 c é                               | v [J].                | c                              | ä                          | , 1999,16(3): 140-146 |                       |                       |                     |   |                     |
| 65                             | o ,   | ,  | .           | z c                                     | x -                   | e? ? ? ? ? ? ? [J].            | c                          | ä                     |                       |                       |                     |   |                     |
| 2000,17(2): 70-73              |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 66                             | ,   | ,  | ?           | ,                                       | ñ e h -               | oy                             | ç SiC <sub>w</sub> /6061Al | c ? ? ? ? ? ? ? ? ?   | ÿ                     |                       |                     |   |                     |
| [J]. c ä , 2000,17(4): 58-62   |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 67                             | ,   | ,  | k ÷         | ÿ .                                     | á? ? ? c              | oy? ? ?                        | ÿ [J].                     | c                     | ä                     | , 2006,23(6):         |                     |   |                     |
| 52-56                          |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 68                             | ,   | ,  | ,           | л .                                     | ó? ? ? ? ? ? ? ? ? ?  | b ü                            | [J].                       | c                     | ä                     | , 2006,23(5): 51      |                     |   |                     |
| -57                            |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 69                             | ,   | .  |             |   | ?                     | c é ü [J].                     | c                          | ä                     | , 2006,23(5): 137-142 |                       |                     |   |                     |
| 70                             | ,   | þ.þ c c ááoy[J]. c ä , 2006,23(6): 179-185 |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 71                             | ,   | ,  | ?,          | .                                       | á oy b                | o [J].                         | c                          | ä                     | , 2006,23(3): 5-9     |                       |                     |   |                     |
| 72                             | ,   | ,  | é oy? ? ? ? | [J]. c                                  | á , 2006,23(2): 65-70 |                                | ÿ                          |                       |                       |                       |                     |   |                     |
| 73                             | ,   | ü, STROEVEN Piet.                          | c           |   |                       | [J].                           | c                          | ä                     | , 2006,23(2): 133-142 |                       |                     |   |                     |
| 74                             | κ, C , .oyb[J]. c ä , 2006,23(1): 161-166   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 75                             | ,   | ,  | .           | l c ? ?                                 | á                     | [J].                           | c                          | ä                     | , 2006,23(2): 175     |                       |                     |   |                     |
| -179                           |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 76                             | ,   | ,  | ?,          | ,                                       | ?                     | é oy                           | a                          | [J].                  | c                     | ä                     |                     |   |                     |
| 2005,22(4): 17-22              |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 77                             | ?   | ,  | ,           | .2D-C/ SiC                              | c é oy                | ð                              | úg' [J].                   | c                     | ä                     | , 2005,22(4): 81-85   |                     |   |                     |
| 78                             | , CFRP áá RC [J]. c ä , 2005,22(4): 156-164 |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 79                             | Φ ,   | ,  | .           | c ? ?                                   | ø                     | ÿ                              | —? ?                       | [J].                  |                       |                       |                     |   |                     |
| c ä , 2007,24(3): 167-172      |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 80                             | 粗,?   | ,  | í ,         | .SiC <sub>w</sub> / AZ91                | c AZ91                | ±                              | í[J].                      | c                     | ä                     | , 2005,22(3): 103     |                     |   |                     |
| -108                           |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 81                             | " ,   | ,  | ,           | ,                                       | , .C/C                |                                | [J].                       | c                     | ä                     | , 2010,27(6): 64      |                     |   |                     |
| -69                            |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 82                             | ,   | Cö   | q ,         | ,                                       | c                     | oy? ? ? ?                      | [J].                       | c                     | ä                     | , 2011,28(1): 206-210 |                     |   |                     |
| 83                             | ,   | ,  | ,           | q c oy                                  |                       | ?                              | [J].                       | c                     | ä                     | , 2011,28(1): 218-222 |                     |   |                     |
| 84                             | ?   | ,  | K ,         | á nn c                                  | oy? ? ? ?             |                                | [J].                       | c                     | ä                     | , 2011,28(1): 230-    |                     |   |                     |
| 234                            |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 85                             | ? ,   | ,  | ,           | /? ? ? ? ? ?                            | é ? ? ? ?             | ý                              | [J].                       | c                     | ä                     | , 2011,28(3):         |                     |   |                     |
| 6-12                           |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 86                             | q , Cö ,                                    | ,  | ,           | CCF300/ ? ? ? ? ?                       | x                     | oy                             | o [J].                     |                       |                       |                       |                     |   |                     |
| c ä , 2011,28(3): 180-184      |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 87                             | öö ,  | ,  | 夥.          | c c x 往                                 | ?                     | [J].                           | c                          | ä                     | , 2011,28(3): 197-202 |                       |                     |   |                     |
| 88                             | ,   | ,  | .           | ?                                       | ób                    | ?                              | [J].                       | c                     | ä                     | , 2011,28(3): 210-216 |                     |   |                     |
| 89                             | ,   | ,  | ,           | η ÷,                                    | .AIN                  | л                              | ?                          | [J].                  | c                     | ä                     |                     |   |                     |
| 2011,28(3): 217-222            |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 90                             | .áo[J]. c ä , 1995,12(3): 125-128           |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 91                             | ,   | ,  | ,           | ,                                       | l .                   | Ni/ ?                          | c oy L                     | ý                     | [J].                  | c                     | ä                   |   |                     |
| c ä , 2011,28(4): 52-57        |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 92                             | ,   | ú ,  | .           | oy                                      | é c                   | 彦                              | ?                          | [J].                  | c                     | ä                     |                     |   |                     |
| 2011,28(4): 202-211            |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 93                             | ¾ ,   | ,  | ü ,         | ,                                       | ó.SiO <sub>2</sub>    |                                | [J].                       | c                     | ä                     | , 2011,28(5): 46-51   |                     |   |                     |
| 94                             | ,   | ,  | ?           | ,                                       | n ö                   | Nb-16Si-22Ti-2Hf-2Cr-2Al       | ?                          | ?                     | ?                     | ?                     | ?                   | ? | ?                   |
| [J]. c ä , 2011,28(5): 133-138 |   |  |             |   |                       |                                |                            |                       |                       |                       |                     |   |                     |
| 95                             | ,   | Φ ,  | ,           | ?                                       | ,                     | é ,                            | á .                        | ?                     | ?                     | ?                     | ?                   | ? | ?                   |

|                           |     |          |       |       |         |                           |              |                   |                    |             |           |             |                       |                       |                     |                     |                  |                     |   |   |
|---------------------------|-----|----------|-------|-------|---------|---------------------------|--------------|-------------------|--------------------|-------------|-----------|-------------|-----------------------|-----------------------|---------------------|---------------------|------------------|---------------------|---|---|
| 2011,28(6): 1-7           | 96  | ,        | ü.    | '     |         | ꝑ                         | oy           | ī                 | ÿ                  | [J].        | c         | ā           | , 2011,28(5): 168-173 |                       |                     |                     |                  |                     |   |   |
|                           | 97  | ,        | -     | ,     | ī.?     | ? ? ?                     | ā? ? ? ? ? ? | c                 | ö                  | 鷗           | [J].      | c           | ā                     | , 2011,28(5): 192-196 |                     |                     |                  |                     |   |   |
|                           | 98  | ? ?,     | .Fe   | ꝑ     | Nb 16Si | λ                         | c            | ? ? ?             |                    | ā ? ?       | ÿ         | [J].        | c                     | ā                     | , 2011,28(6): 172-  |                     |                  |                     |   |   |
| 179                       | 99  | ,        | ✉     | ,     | .       | á                         | 1×1?         | ?                 | c                  | þ           | ſ         |             |                       |                       | [J].                | c                   | ā                | ,                   |   |   |
| 2011,28(6): 215-222       | 100 | lu       | ?,    | ,     | c,      | ,                         |              | .SiO <sub>2</sub> |                    | STF/Kevlar  | c         | p ? ? ? ? ? | ÿ                     | [J].                  |                     |                     |                  |                     |   |   |
| c ā , 2012,29(1): 54-61   | 101 | ,        | ꝑ     | ,     | ,       | ? ? .                     |              | PMI               | o                  | c ? ? ? ? ? | ÿ         | [J].        | c                     | ā                     | , 2012,(2): 46-     |                     |                  |                     |   |   |
| 52                        | 102 | 2? ? ? , | ? ? - | ,     | ,       | .                         | ð            | 遇                 | c                  | c           |           |             |                       |                       | c                   | ā                   | , 2012,(2): 130- |                     |   |   |
| 134                       | 103 | ,        | ✉     | ,?    | .       | þ                         | c            | c                 | !                  |             | oy        | o           | [J].                  | c                     | ā                   | , 2012,(2): 160-166 |                  |                     |   |   |
| c ā , 2012,(2): 180-185   | 104 | ,        | ¼?    | ,     | ,       | ,                         | .            | .Z                | o                  | c           | j         |             | oy                    | [J].                  |                     |                     |                  |                     |   |   |
| c ā , 2012,(2): 205-212   | 105 | ,        | ¼?    | ,     | ,       | ,                         | .            | oySMAT            | 304?               | ?? ? ? ?    | ~         |             |                       |                       |                     |                     |                  |                     |   |   |
| 106                       | ŋ   | ,        | ꝑ     | ,     | ¼       | ,                         | .            | ?                 | ā? ? ? ? ?         | ?           |           | [J].        | c                     | ā                     | , 2012,(3): 42-48   |                     |                  |                     |   |   |
| 107                       | -   | ,        | ,     | ,     | ²       | ,                         | .            | c                 | c                  | 忪           | oy        | [J].        | c                     | ā                     | , 2012,(3): 167-172 |                     |                  |                     |   |   |
| 108                       | ,   | ,        | ,     | ,     | ?       | .                         |              |                   | ōb                 |             | o         | [J].        | c                     | ā                     | , 2012,(3): 184-190 |                     |                  |                     |   |   |
| 109                       | ī,  | ‡        | ,     | ,     | ✉.      | ? ? ? ? ? ? ? ? ? ? ? ? ? | c            | oy                | ā                  | [J].        | c         | ā           | , 2012,(4): 224-230   |                       |                     |                     |                  |                     |   |   |
| 110                       | ²   | ,        | -     | ,     | ,       | ī.                        | ð            | 遇                 | c                  | ✉           |           | [J].        | c                     | ā                     | , 2012,(5): 151-156 |                     |                  |                     |   |   |
| 111                       | ꝑ   | ,        | ✉     | .     | !       |                           | c            | c                 | x                  | oy          |           | o           | [J].                  | c                     | ā                   | , 2012,(5): 171-178 |                  |                     |   |   |
| (5): 171-178              | 112 | ,        | ,     | ë     | .       |                           | 渴            | c                 | C                  | ? ? ? ? ?   | ÿ         | [J].        | c                     | ā                     | , 2012,(5): 191     |                     |                  |                     |   |   |
| -195                      | 113 | ÷        | ,     | ,     |         | .SiC/Ti-6Al-4V            | c            | ɛ?                | ? ? ? ? ?          | ?           | o         | ½           | Ȑ                     | ī?                    | ? ?                 | ~                   | [J].             | c                   | ā | , |
| 2012,(6): 159-163         | 114 | k        | ,     | ,     | ,       | ÿ .                       | ā? ? ? ? /?  | c                 | oy                 | ɛ           |           |             | ā                     | ī                     | [J].                | c                   | ā                | , 2012,(6): 206-211 |   |   |
| 6): 206-211               | 115 | ? ΘΘ,    | ,     | ü,    | ,       | ,                         | C            | ,Φ                | .K-cor             | B           |           | ā           | [J].                  | c                     | ā                   | , 2012,(6): 230-236 |                  |                     |   |   |
| 116                       | ,   | ,        | .     | á     |         | ð                         | c            |                   | Ȑ?                 | ? ?         | ā? ?      | ~           | [J].                  | c                     | ā                   | , 1997,14(3): 81-86 |                  |                     |   |   |
| c ā , 1997,14(2): 114-119 | 117 | ,        | ü.    | oy    |         | /                         |              | c                 | c                  | 僻           |           |             | "                     | o                     | [J].                |                     |                  |                     |   |   |
| c ā , 0,(): 114-119       | 118 | ,        | ü.    | oy    |         | /                         |              | c                 | c                  | 僻           |           |             | "                     | o                     | [J].                |                     |                  |                     |   |   |
| 21-26                     | 119 | ,        | ,     | -q    | ,       | ꝑ                         | .            | ā                 |                    | ɛ           |           | ÿ           | [J].                  | c                     | ā                   | , 1996,13(3):       |                  |                     |   |   |
| 120                       | ,   | ,        | .     |       | 临       | c                         |              | ö                 |                    |             |           | [J].        | c                     | ā                     | , 1995,12(4): 90-93 |                     |                  |                     |   |   |
| 121                       | C   | ,        | C     | ,     | M       | .SiO <sub>2</sub>         | ?            | c                 | ā ? ? ?            |             | o         | [J].        | c                     | ā                     | , 1994,11(4): 69-75 |                     |                  |                     |   |   |
| 122                       | .   | c        | c     |       |         |                           |              | ö                 |                    |             |           | [J].        | c                     | ā                     | , 1994,11(3): 76-81 |                     |                  |                     |   |   |
| 123                       | .   | c        | M     |       | oy?     | ? ? ? ?                   | o            | [J].              | c                  | ā           |           |             |                       |                       |                     |                     |                  |                     |   |   |
| 124                       | ,   | ,        |       | .     | [±      | /90 <sub>2</sub> ]? /     |              |                   | Ȑ?                 | ? ?         | ~         | L           | [J].                  | c                     | ā                   | , 1993,10(2): 39-45 |                  |                     |   |   |
| 125                       | ,   | ,        | ā     |       | c       | c                         | ñ?           | ~                 | o                  | [J].        | c         | ā           |                       |                       |                     |                     |                  |                     |   |   |
| 126                       | ,   | ,        | ñ     |       | C       | .                         | ö            |                   | Ȑ?                 | ? ? ? ? ?   | ?         | ÿ           | [J].                  | c                     | ā                   | , 2013,30(1): 54-61 |                  |                     |   |   |
| 127                       | ,   | ,        |       | .CFRP | c       | c                         | ꝑ            |                   | oy?                | ? ? ? ? ?   | ?         | ~           | [J].                  | c                     | ā                   | , 2013,30(2): 159-  |                  |                     |   |   |
| 164                       | 128 | ,        | ?     | +     | ,       | ,                         | ?            | .                 | TiO <sub>2</sub> ? | ? ? ? ? ?   | ?         | ?           |                       | c                     | M                   | ā                   | ī                | [J].                |   |   |
| c ā , 2013,30(1): 236-243 | 129 | ,        | ?     | ,     | ?       | .                         | u            | v?                | ? ? ? ? ?          | ā           |           |             |                       | c                     | ā                   | ,                   |                  |                     |   |   |
| 2013,30(1): 244-251       |     |          |       |       |         |                           |              |                   | Ȑl                 | c           | ? ? ? ? ? | ?           | ?                     | [J].                  | c                   | ā                   | ,                |                     |   |   |

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