ADVANCED ENERGY MATERIALS

# Supporting Information

for *Adv. Energy Mater.,* DOI: 10.1002/aenm.201401391

## Mechanically Robust BiSbTe Alloys with Superior Thermoelectric Performance: A Case Study of Stable Hierarchical Nanostructured Thermoelectric Materials

*Yun Zheng, Qiang Zhang, Xianli Su,* Hongyao Xie, Shengcheng Shu, Tianle Chen, Gangjian Tan, Yonggao Yan, Xinfeng Tang,* Ctirad Uher, and G. Jeffrey Snyder*

# Supporting Information

**Mechanical robust BiSbTe alloys with superior thermoelectric performance: A case study of stable hierarchical nanostructured thermoelectric materials**

Yun Zheng, Qiang Zhang, Xianli Su,* Hongyao Xie, Shengcheng Shu, Tianle Chen, Gangjian Tan, Yonggao Yan, Xinfeng Tang,* Ctirad Uher and G. Jeffrey Snyder

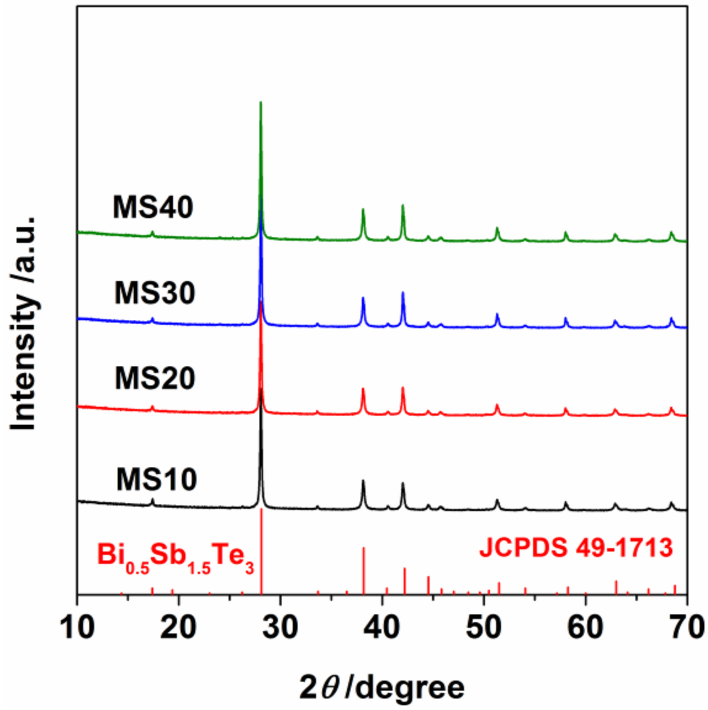


**Figure S1.** XRD patterns of MS powders before sintering.

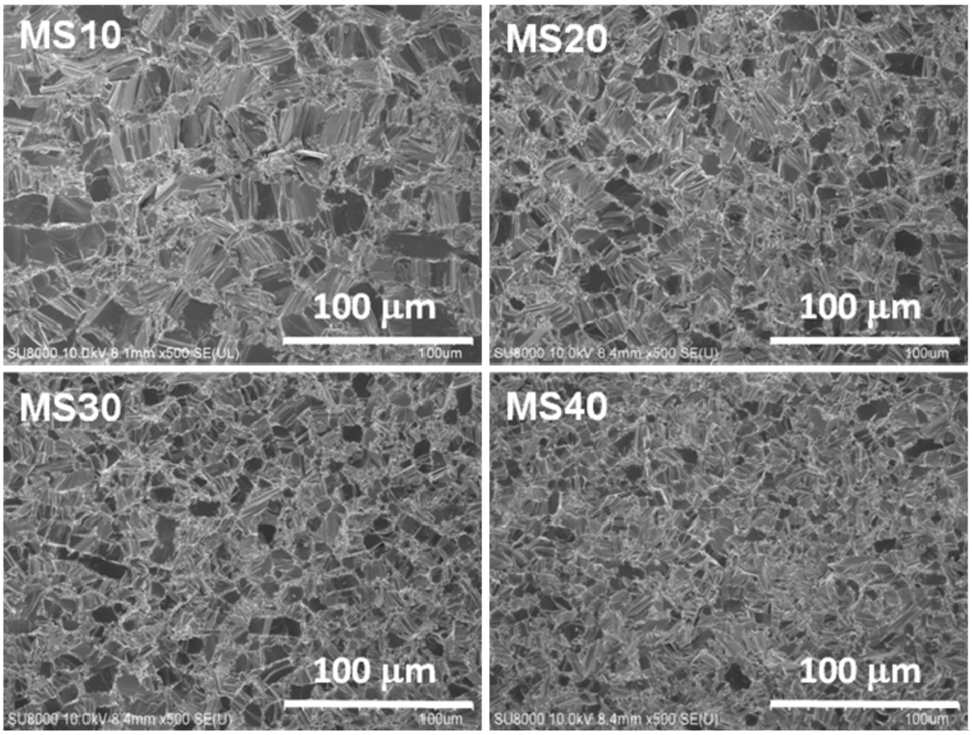


**Figure S2.** Free fracture surfaces of MS-PAS samples.

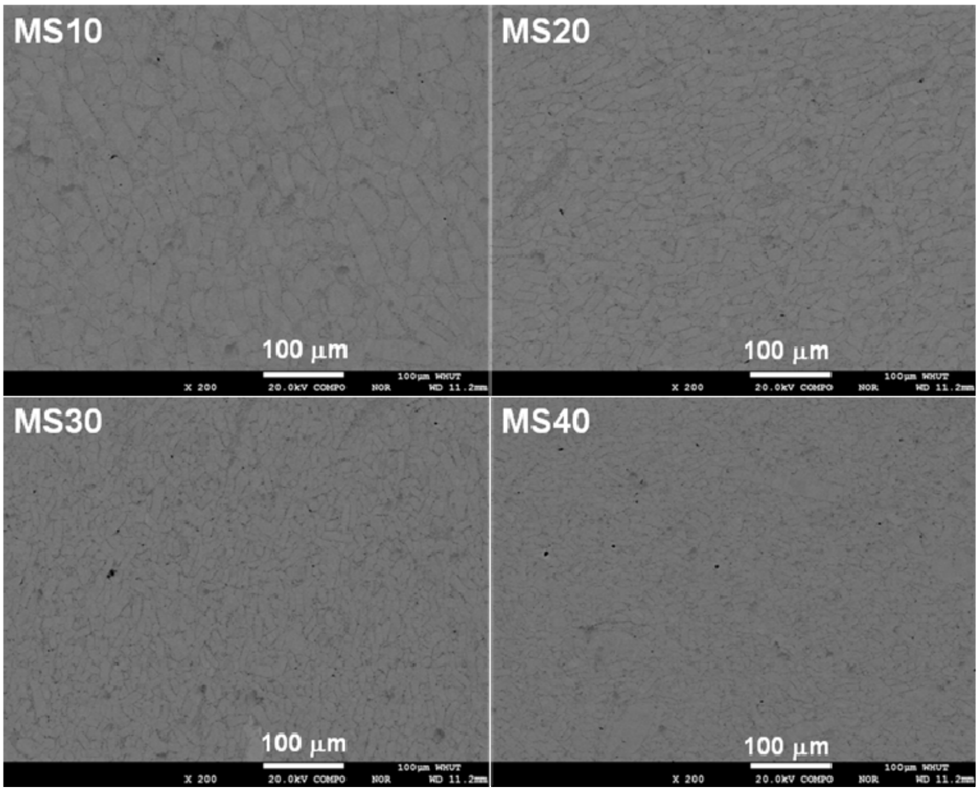


**Figure S3.** Backscattered electron (BSE) images of polished surfaces of MS-PAS samples.

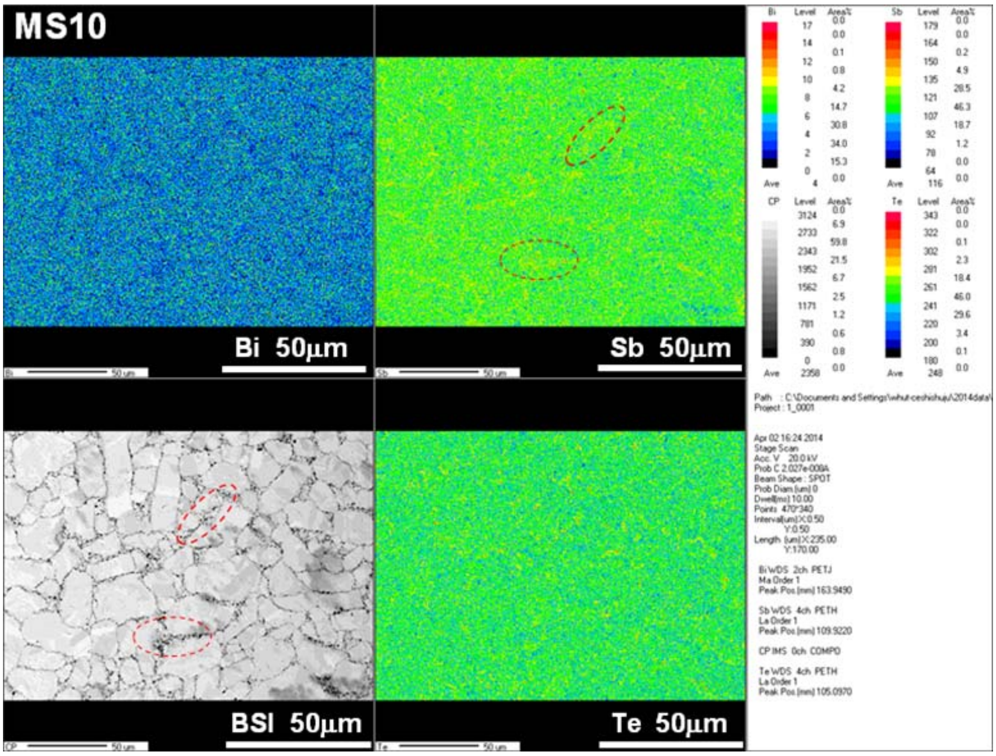


**Figure S4.** Backscattering image (BSI) and elemental mapping of Bi, Sb and Te of carefully polished surface for MS10 sample.

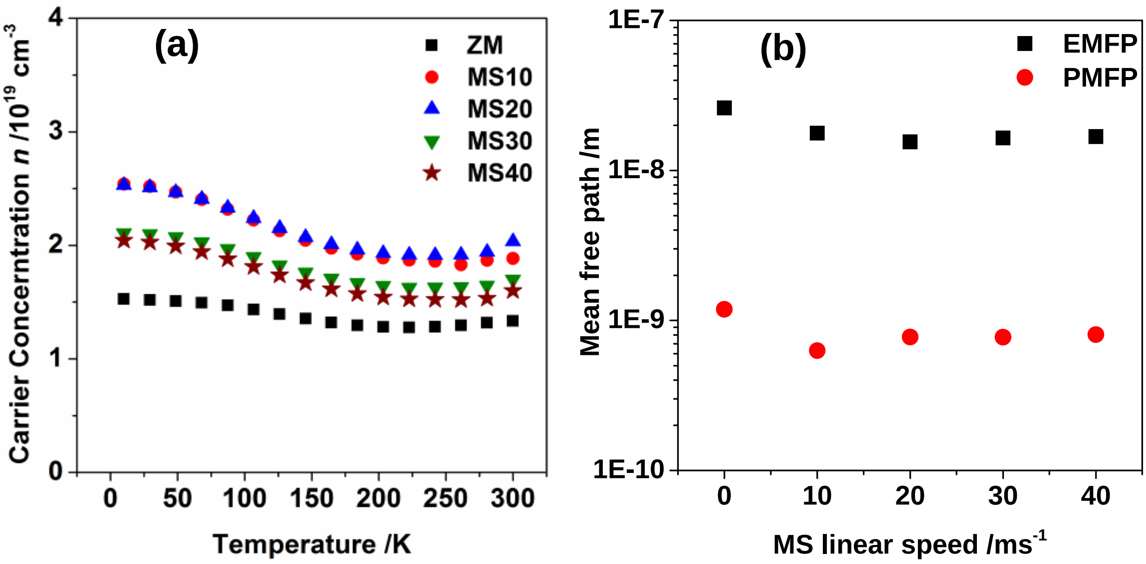


**Figure S5.** (a) Temperature dependence of carrier concentration of ZM and MS-PAS bulk specimens. (b) Electron and phonon mean free path donoted as EMFP and PMFP, respectively, as a function of MS linear speed. The linear speed of 0 m/s corresponds to the ZM ingot.

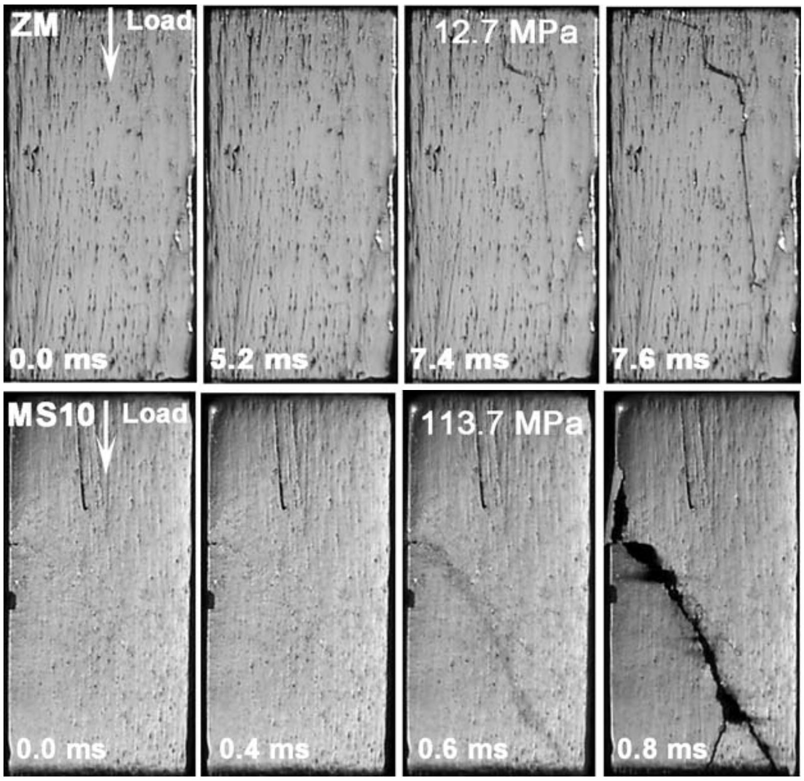


**Figure S6.** High speed video observations of crack propagation in compressive test for ZM and MS10 samples.

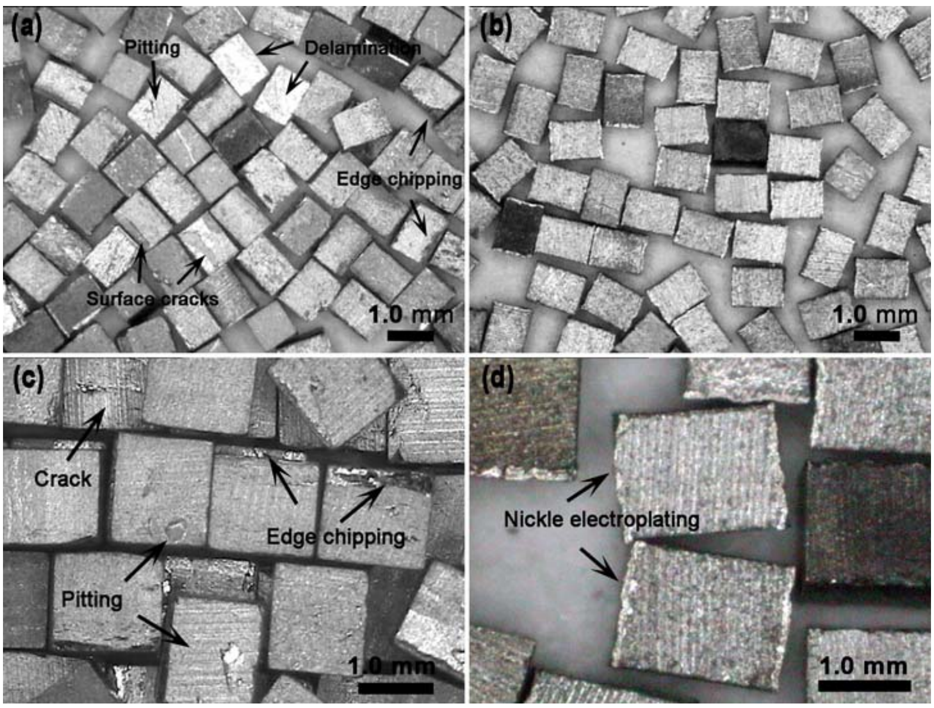


**Figure S7.** Optical images of micro bricks (dimension 1.6×1.4×1.4 $mm^3$) cut from (a) (c) ZM ingots and (b) (d) MS10 specimens. The arrows indicate the machining defects in ZM ingots such as surface cracks, edge chipping, pitting and delamination.

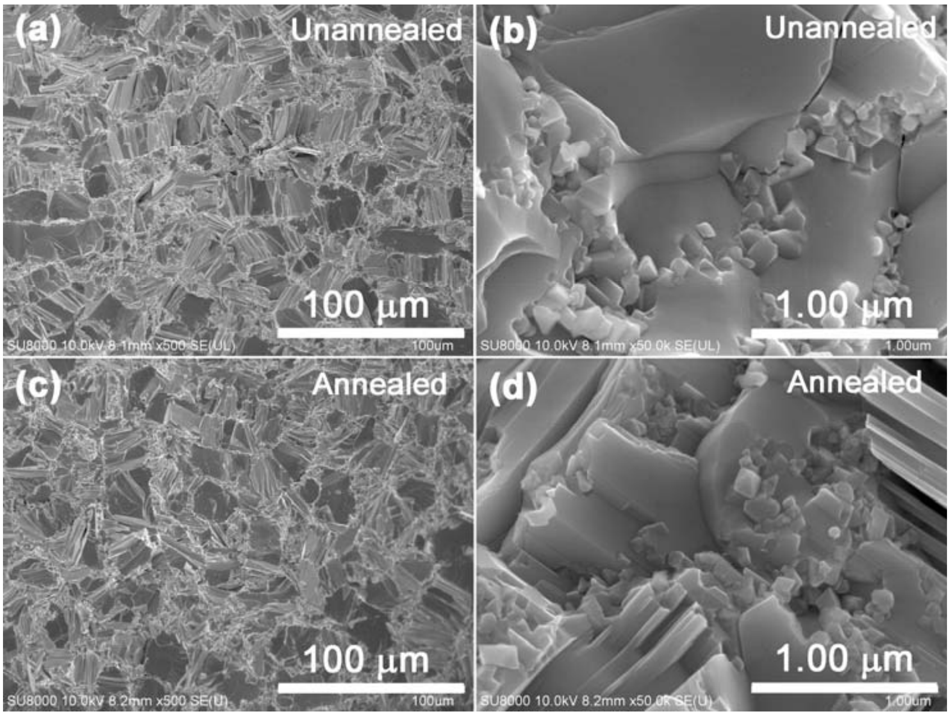


**Figure S8** FESEM images of free fracture surface of (a)-(b) unannealed and (c)-(d) annealed MS10 specimens.

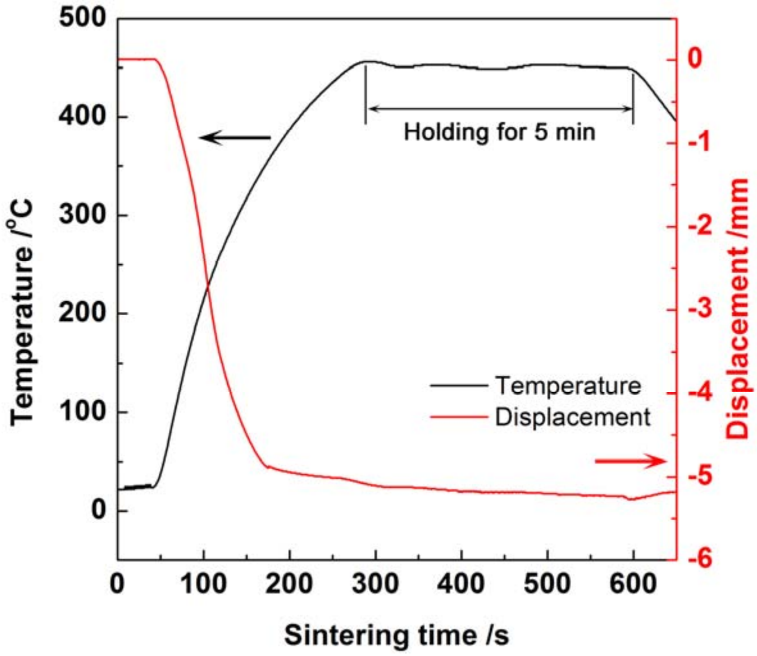


**Figure S9.** Plasma activated sintering profile of $Bi_{0.5}Sb_{1.5}Te_3$ powders.

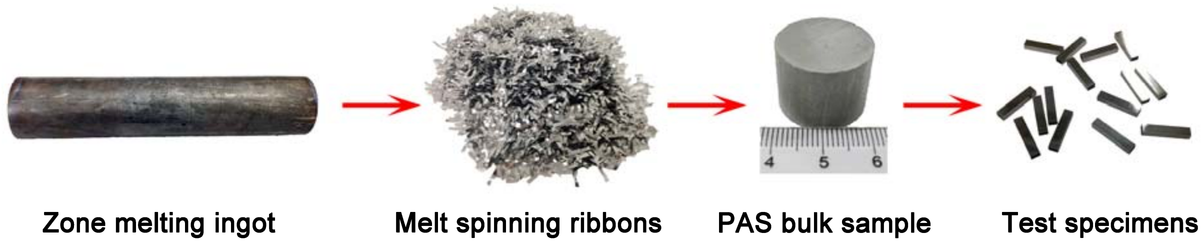


**Figure S10.** The flow chart of MS-PAS process. The size of PAS bulk material is Φ20x15 mm.

**Table S1** The table lists the number of samples measured at room temperature, 100 $^{o}$C and 200 $^{o}$C, and temperature dependent flexural strength of ZM and MS-PAS samples fitted by Weibull distribution.

| Specimen | Temperature [$^{o}$C] | Number of samples | Characteristic strength [Mpa] | Weibull modulus |
|---|---|---|---|---|
| ZM | 25 | 12 | 9.6 (6.1, 12.2) | 3.2 (1.2, 5.3) |
| MS10 | 25 | 16 | 65.2 (51.8, 70.7) | 11.4 (10.0, 12.7) |
| | 100 | 14 | 65.6 (53.4, 76.5) | 9.6 (7.9, 11.4) |
| | 200 | 11 | 56.3 (50.2, 61.5) | 13.2 (9.8, 16.6) |
| MS20 | 25 | 15 | 66.2 (55.8, 72.7) | 12.2 (10.5, 13.9) |
| | 100 | 10 | 70.1 (54.8, 76.5) | 10.0 (8.4, 11.7) |
| | 200 | 10 | 61.1 (47.6, 65.1) | 10.2 (7.8, 12.6) |
| MS30 | 25 | 12 | 64.0 (57.2, 73.0) | 12.8 (7.7, 18.0) |
| | 100 | 10 | 65.2 (59.9, 72.6) | 13.0 (8.2, 17.8) |
| | 200 | 11 | 61.7 (46.3, 68.7) | 8.4 (6.8, 10.0) |
| MS40 | 25 | 14 | 69.6 (54.0, 80.8) | 6.8 (5.4, 8.2) |
| | 100 | 12 | 72.8 (66.2, 77.9) | 18.5 (15.2, 21.8) |
| | 200 | 11 | 65.1 (54.9, 70.7) | 11.5 (9.1, 13.9) |

**Table S2.** The table lists the number of samples measured at room temperature, 100 $^{o}C$ and 200 $^{o}C$, and temperature dependent compressive strength of ZM and MS-PAS samples fitted by Weibull distribution.

| Specimen | Temperature [$^{o}C$] | Number of samples | Characteristic strength [Mpa] | Weibull modulus |
|---|---|---|---|---|
| ZM | 25 | 14 | 12.7 (6.3, 18.0) | 3.6 (2.9, 4.2) |
| | 100 | 15 | 10.2 (6.7, 12.7) | 4.3 (3.1, 5.6) |
| | 200 | 15 | 10.7 (7.0, 13.4) | 5.7 (5.0, 6.5) |
| MS10 | 25 | 13 | 113.7 (59.8, 140.1) | 4.0 (3.5, 4.5) |
| | 100 | 11 | 96.3 (64.7, 140.8) | 3.3 (2.2, 4.5) |
| | 200 | 10 | 84.6 (71.2, 88.3) | 18.4 (14.1, 22.7) |
| MS20 | 25 | 15 | 133.7 (106.0, 144.4) | 15.2 (11.5, 18.9) |
| | 100 | 14 | 108.2 (88.0, 111.0) | 14.3 (9.2, 19.4) |
| | 200 | 15 | 94.1 (78.1, 96.6) | 12.4 (8.8, 16.0) |
| MS30 | 25 | 11 | 116.3 (100.7, 122.6) | 14.9 (11.6, 18.3) |
| | 100 | 10 | 101.6 (90.9, 104.8) | 17.6 (10.8, 24.4) |
| | 200 | 10 | 95.4 (75.3, 99.3) | 21.9 (12.0, 31.9) |
| MS40 | 25 | 14 | 135.3 (110.5, 155.5) | 17.8 (13.6, 22.0) |
| | 100 | 12 | 119.4 (92.8, 131.1) | 14.3 (10.2, 18.4) |
| | 200 | 11 | 111.8 (98.6, 115.6) | 19.5 (16.3, 22.7) |