

GB/T 228.1—2010 中最大力塑性延伸率测量新方法及其验证

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摘要:根据 GB/T 228.1—2010 标准中金属材料最大力塑性延伸率的定义及公式, 结合材料变形的物理原理及卸载定律, 建立了一种新的金属材料最大力塑性延伸率测量方法。结果表明: 该方法既符合 GB/T 228.1—2010 标准中对最大力塑性延伸率的定义, 又克服了引伸计测量法的缺点。

关键词:拉伸试验; 测量方法; 最大力塑性延伸率; 标准

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New measurement method and its verification for maximum force plastic elongation in GB/T 228.1—2010

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Abstract: According to the definition and formula of maximum force plastic elongation of metallic materials in GB/T 228.1—2010 standard, a new measurement method of maximum force plastic elongation of metallic materials was established based on the physical principle of material deformation and unloading law. The results show that the method not only conformed to the definition of maximum force plastic elongation in GB/T 228.1—2010 standard, but also overcame the shortcomings of extensometer measurement method.

Keywords: tensile test; measurement method; maximum force plastic elongation; standard

最大力塑性延伸率 A_g 是 GB/T 228.1—2010 《金属材料 拉伸试验 第 1 部分: 室温试验方法》中表征金属材料力学性能的一个重要指标, 其基本定义是最大力时原始标距的塑性延伸与引伸计标距之比的百分率。标准给出的测量方法为: 在用引伸计得到的力-延伸曲线上, 从最大力时的总延伸中扣除弹性延伸部分, 即得到最大力时的塑性延伸, 将其除以引伸计标距得到 A_g 。计算公式为

$$A_g = \left(\frac{\Delta L_m}{L_e} - \frac{R_m}{m_g} \right) \times 100\% = (A_{gt} - \epsilon_e) \times 100\% \quad (1)$$

式中: ΔL_m 为最大力时的总延伸长度; L_e 为引伸计标距; R_m 为抗拉强度; m_g 为应力-延伸率曲线弹性部分的斜率; A_{gt} 为最大力总延伸率; ϵ_e 为力-延伸曲线上弹性部分的应变。

先在拉伸试验过程中的拉伸曲线的最大力处读出引伸计给出的伸长率, 将该值作为材料的最大力总延伸率, 然后在力-延伸曲线上求出弹性应变 ϵ_e , 再根据式(1)计算出最大力塑性延伸率。这一方法通常被称为引伸计法, 虽然该方法直观、科学、准确, 但容易受到引伸计的引伸距离不够长、测试时不够安全, 以及测量时操作人员精力分散的影响。

依据金属材料变形的物理原理及卸载定律, 建立了一个新的材料最大力塑性延伸率的测量方法, 该方法既能符合 GB/T 228.1—2010 给出的最大力塑性延伸率的定义, 又能克服利用引伸计法测量的各种缺点, 实现科学有效、简便安全的测量。

1 测量原理

材料在外力的作用下会产生变形, 且随着外力的增加, 材料的变形增加, 直至断裂。典型的金属材料拉伸曲线如图 1 所示。

如果当应力小于弹性极限时停止加载, 并将载

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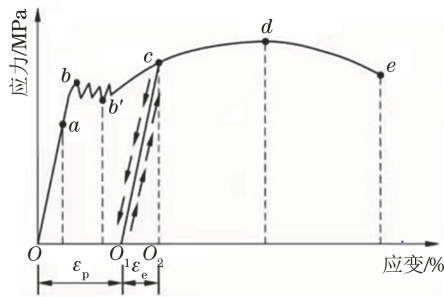


图1 典型的金属材料拉伸曲线

荷逐渐减小至零,即卸去载荷,则可以看到,在卸载过程中,应力-应变曲线将沿着原路径 aO 回到 O 点(见图1),变形完全消失;如果在超过弹性极限后,如在硬化阶段,某一点 c 的载荷逐渐减小,则卸载过程中的应力-应变曲线如图1中的 cO_1 所示,该直线与 Oa 几乎平行。线段 O_1O_2 代表随卸载而消失的应变,即弹性应变 ϵ_e ;而线段 OO_1 则代表应力减小至零时残留的应变,即塑性应变或残余应变 ϵ_p 。由此可见,当应力超过弹性极限后,材料的应变包括弹性应变 ϵ_e 和塑性应变 ϵ_p ,但在卸载过程中,应力与应变之间仍保持线性关系,即 $\Delta\sigma = \Delta\epsilon$,这称为卸载定律^[1]。

该方法的基本思路是在金属材料拉伸曲线上达到最大应力处立即停止施加外力并卸载,然后取下试样,根据卸载定律,当卸载后,弹性变形部分消失,只保留了塑性变形部分。这样,最大力处卸载后测量的试样的伸长即为塑性伸长,按 GB/T 228.1—2010 给出的定义,即可计算出 A_g 。即

$$A_g = \frac{\Delta L_g}{L_e} \times 100\% \quad (2)$$

式中: ΔL_g 为最大力时的塑性延伸长度; L_e 为引伸计标距。

该方法的创新之处为:科学利用材料变形的物理原理及卸载定律,结合最大力塑性延伸率的定义,建立了一个科学有效、简便安全的材料最大力塑性延伸率的直接测量方法。

2 测量方法

2.1 试样

以牌号分别为 HRB400, HRB400E, HRB600, HRB500E, HRBF400, HRBF500E 的国产热轧螺纹钢为试验对象,每 10 个试样为一组(具有相同的牌号和规格),试样来自不同的生产厂家和炉批号。测量结果与已有足够引伸距离引伸计的直接测量结果进行比较。螺纹钢试样表面状态符合 GB/T

228.1—2010 的有关要求,试样夹具间的最小自由长度如表 1 所示。

表1 螺纹钢试样夹具间的最小自由长度

| 螺纹钢公称直径 | 试样夹具之间的最小自由长度 |
|------------------|---------------|
| $d \leq 25$ | 350 |
| $25 < d \leq 32$ | 400 |
| $32 < d \leq 50$ | 500 |

在试样的自由长度范围内,均匀划分为 10 mm 或 5 mm 的等距标距,标距的划分和测量应符合 GB/T 228.1—2010 的有关规定。

2.2 测量方法

按照 GB/T 228.1—2010 进行螺纹钢的拉伸试验,当应力-应变曲线达到应力最大值时,立即停止加载并卸载,然后取下试样并进行测量。

以试样自由长度处的 100 mm 为初始长度 L_0 ,测量试样最大力时的伸长 L_p 。按照材料拉伸时的卸载定律,卸载后测量到的伸长 L_p 即为最大力时的塑性伸长,按照式(2)即可计算出螺纹钢的最大力塑性延伸率 A_g 。

3 测量结果及验证

利用上述方法,采用电子拉力试验机(INSTRON 5500R)和万能材料试验机(INSTRON 5592)以相同的速率对不同牌号螺纹钢的最大力塑性延伸率进行了测量,并与引伸计直接读数法的测量结果进行比较,结果如表 2 所示。

表2 螺纹钢最大力塑性延伸率测量值与引伸计

| 试样牌号 与规格/mm | 直接读数法的测量结果比较 | | | 平均相对 误差绝对 值/% |
|-------------------|-------------------|--------------|-------------------------|---------------------|
| | 最大力塑性延伸率/% 测量值 | 引伸计法 的测量值 | 与引伸计 法测量值的 相对误差/% | |
| HRB400, $\phi 10$ | 12.0 | 11.5 | 4.3 | 2.29 |
| | 15.0 | 14.5 | 3.4 | |
| | 11.5 | 11.5 | 0 | |
| | 12.0 | 12.5 | -4.0 | |
| | 14.5 | 14.5 | 0 | |
| | 12.5 | 12.0 | 3.8 | |
| | 13.5 | 14.0 | -3.6 | |
| | 13.5 | 13.5 | 0 | |
| | 14.5 | 14.5 | 0 | |
| | 12.5 | 13.0 | -3.8 | |

表 2 (续)

| 试样牌号 与规格/mm | 最大力塑性延伸率/% | | 与引伸计 法测量值的 相对误差/% | 平均相对 误差绝对 值/% |
|--------------------|------------|--------------|-------------------------|---------------------|
| | 测量值 | 引伸计法 的测量值 | | |
| HRB400E, $\phi 16$ | 13.0 | 13.0 | 0 | 2.57 |
| | 15.5 | 15.0 | 3.3 | |
| | 13.5 | 13.0 | 3.8 | |
| | 13.0 | 13.5 | -3.7 | |
| | 12.0 | 12.0 | 0 | |
| | 12.5 | 12.0 | 4.2 | |
| | 13.0 | 13.0 | 0 | |
| | 13.5 | 13.0 | 3.8 | |
| | 14.5 | 14.0 | 3.6 | |
| HRB600, $\phi 12$ | 14.5 | 15.0 | -3.3 | 2.31 |
| | 12.5 | 13.0 | -3.8 | |
| | 13.5 | 13.5 | 0 | |
| | 12.5 | 12.5 | 0 | |
| | 13.0 | 12.5 | 4.0 | |
| | 13.0 | 13.0 | 0 | |
| | 14.5 | 14.0 | 3.6 | |
| | 14.0 | 13.5 | 3.7 | |
| | 12.0 | 11.5 | 4.3 | |
| HRB500E, $\phi 25$ | 13.0 | 13.5 | -3.7 | 2.51 |
| | 13.5 | 13.5 | 0 | |
| | 12.5 | 12.0 | 4.2 | |
| | 13.5 | 14.0 | -3.6 | |
| | 13.0 | 12.5 | 4.0 | |
| | 15.0 | 15.5 | -3.2 | |
| | 14.5 | 14.5 | 0 | |
| | 15.5 | 16.0 | -3.1 | |
| | 15.5 | 15.0 | 3.3 | |
| HRBF400, $\phi 32$ | 14.5 | 14.5 | 0 | 2.10 |
| | 12.5 | 12.5 | 0 | |
| | 13.0 | 13.5 | -3.7 | |
| | 15.5 | 15.5 | 0 | |
| | 15.5 | 15.0 | 3.3 | |
| | 14.0 | 14.0 | 0 | |
| | 13.5 | 13.5 | 0 | |
| | 16.0 | 15.5 | 3.1 | |
| | 14.0 | 14.0 | 0 | |
| 16.0 | 15.5 | 3.2 | | |
| 13.5 | 13.0 | 3.8 | | |
| 13.5 | 14.0 | -3.6 | | |
| 13.0 | 12.5 | 4.0 | | |

由表 2 可知,该方法测量的螺纹钢最大力塑性延伸率与引伸计法测量的结果有很好的 consistency。

4 不确定度评估

依据 GB/T 228.1—2010 附录 L 对断后伸长率不确定度的评定,其测量不确定度主要来源于 4 个方面:测量重复性、试样原始标距^[2]、断后伸长率及数值修约,其相对标准不确定度分别为 1.31%, 0.58%, 1.32%, 0.66%。断后伸长率的相对合成不确定度为 2.05%, 相对扩展不确定度为 4.1%。

与断后伸长率的测量方法不同,测量螺纹钢最大力塑性延伸率时,拉伸试验时无法立即确定拉伸应力是否到了最高点,只有当拉伸应力不继续上升或瞬时开始下降时才能确定拉伸应力已经到了最高点,因此在实际测量时会因为检验人员的经验及能力带来一定测量误差。笔者认为这部分的不确定度属于测量重复性。依据 GB/T 28900—2012《钢筋混凝土用钢材试验方法》,测量重复性带来的偏离值约为 0.2%,将该数值加到测量重复性的相对标准不确定度中,并依据 GB/T 228.1—2010 附录 L,可计算出测量重复性相对不确定度为 1.833%,其他试样的原始标距、断后伸长及数值修约的相对标准不确定度不变。这样就可计算出上述方法测量 A_g 的相对合成不确定度为 2.42%, 相对扩展不确定度为 4.84%。

5 结语

依据材料变形的物理原理及卸载定律,并结合 GB/T 228.1—2010 给出的 A_g 的定义,建立了一种新的金属材料 A_g 的测量方法,与引伸计法的测量结果具有很好的 consistency,在实际测量中具有很好的操作性。

理论和验证试验证明该方法可以作为大生产检验的辅助方法,但建议仲裁试验时使用引伸计法。

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(7) 作者简介 第一作者简介:姓名(出生年-),性别,职称,学位,研究方向及邮箱。如有第一作者以外的通信作者,同时应注明通信作者:姓名(出生年-),性别,职称,学位,研究方向及邮箱。

(8) 正文 正文一般包括引言、原理、方法、结果、讨论、结论等部分。其中,引言部分不写编号和标题。除引言外,其余部分可加分标题,一级标题用1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128,129,130,131,132,133,134,135,136,137,138,139,140,141,142,143,144,145,146,147,148,149,150,151,152,153,154,155,156,157,158,159,160,161,162,163,164,165,166,167,168,169,170,171,172,173,174,175,176,177,178,179,180,181,182,183,184,185,186,187,188,189,190,191,192,193,194,195,196,197,198,199,200,201,202,203,204,205,206,207,208,209,210,211,212,213,214,215,216,217,218,219,220,221,222,223,224,225,226,227,228,229,230,231,232,233,234,235,236,237,238,239,240,241,242,243,244,245,246,247,248,249,250,251,252,253,254,255,256,257,258,259,260,261,262,263,264,265,266,267,268,269,270,271,272,273,274,275,276,277,278,279,280,281,282,283,284,285,286,287,288,289,290,291,292,293,294,295,296,297,298,299,300,301,302,303,304,305,306,307,308,309,310,311,312,313,314,315,316,317,318,319,320,321,322,323,324,325,326,327,328,329,330,331,332,333,334,335,336,337,338,339,340,341,342,343,344,345,346,347,348,349,350,351,352,353,354,355,356,357,358,359,360,361,362,363,364,365,366,367,368,369,370,371,372,373,374,375,376,377,378,379,380,381,382,383,384,385,386,387,388,389,390,391,392,393,394,395,396,397,398,399,400,401,402,403,404,405,406,407,408,409,410,411,412,413,414,415,416,417,418,419,420,421,422,423,424,425,426,427,428,429,430,431,432,433,434,435,436,437,438,439,440,441,442,443,444,445,446,447,448,449,450,451,452,453,454,455,456,457,458,459,460,461,462,463,464,465,466,467,468,469,470,471,472,473,474,475,476,477,478,479,480,481,482,483,484,485,486,487,488,489,490,491,492,493,494,495,496,497,498,499,500,501,502,503,504,505,506,507,508,509,510,511,512,513,514,515,516,517,518,519,520,521,522,523,524,525,526,527,528,529,530,531,532,533,534,535,536,537,538,539,540,541,542,543,544,545,546,547,548,549,550,551,552,553,554,555,556,557,558,559,560,561,562,563,564,565,566,567,568,569,570,571,572,573,574,575,576,577,578,579,580,581,582,583,584,585,586,587,588,589,590,591,592,593,594,595,596,597,598,599,600,601,602,603,604,605,606,607,608,609,610,611,612,613,614,615,616,617,618,619,620,621,622,623,624,625,626,627,628,629,630,631,632,633,634,635,636,637,638,639,640,641,642,643,644,645,646,647,648,649,650,651,652,653,654,655,656,657,658,659,660,661,662,663,664,665,666,667,668,669,670,671,672,673,674,675,676,677,678,679,680,681,682,683,684,685,686,687,688,689,690,691,692,693,694,695,696,697,698,699,700,701,702,703,704,705,706,707,708,709,710,711,712,713,714,715,716,717,718,719,720,721,722,723,724,725,726,727,728,729,730,731,732,733,734,735,736,737,738,739,740,741,742,743,744,745,746,747,748,749,750,751,752,753,754,755,756,757,758,759,760,761,762,763,764,765,766,767,768,769,770,771,772,773,774,775,776,777,778,779,780,781,782,783,784,785,786,787,788,789,790,791,792,793,794,795,796,797,798,799,800,801,802,803,804,805,806,807,808,809,810,811,812,813,814,815,816,817,818,819,820,821,822,823,824,825,826,827,828,829,830,831,832,833,834,835,836,837,838,839,840,841,842,843,844,845,846,847,848,849,850,851,852,853,854,855,856,857,858,859,860,861,862,863,864,865,866,867,868,869,870,871,872,873,874,875,876,877,878,879,880,881,882,883,884,885,886,887,888,889,890,891,892,893,894,895,896,897,898,899,900,901,902,903,904,905,906,907,908,909,910,911,912,913,914,915,916,917,918,919,920,921,922,923,924,925,926,927,928,929,930,931,932,933,934,935,936,937,938,939,940,941,942,943,944,945,946,947,948,949,950,951,952,953,954,955,956,957,958,959,960,961,962,963,964,965,966,967,968,969,970,971,972,973,974,975,976,977,978,979,980,981,982,983,984,985,986,987,988,989,990,991,992,993,994,995,996,997,998,999,1000,1001,1002,1003,1004,1005,1006,1007,1008,1009,1010,1011,1012,1013,1014,1015,1016,1017,1018,1019,1020,1021,1022,1023,1024,1025,1026,1027,1028,1029,1030,1031,1032,1033,1034,1035,1036,1037,1038,1039,1040,1041,1042,1043,1044,1045,1046,1047,1048,1049,1050,1051,1052,1053,1054,1055,1056,1057,1058,1059,1060,1061,1062,1063,1064,1065,1066,1067,1068,1069,1070,1071,1072,1073,1074,1075,1076,1077,1078,1079,1080,1081,1082,1083,1084,1085,1086,1087,1088,1089,1090,1091,1092,1093,1094,1095,1096,1097,1098,1099,1100,1101,1102,1103,1104,1105,1106,1107,1108,1109,1110,1111,1112,1113,1114,1115,1116,1117,1118,1119,1120,1121,1122,1123,1124,1125,1126,1127,1128,1129,1130,1131,1132,1133,1134,1135,1136,1137,1138,1139,1140,1141,1142,1143,1144,1145,1146,1147,1148,1149,1150,1151,1152,1153,1154,1155,1156,1157,1158,1159,1160,1161,1162,1163,1164,1165,1166,1167,1168,1169,1170,1171,1172,1173,1174,1175,1176,1177,1178,1179,1180,1181,1182,1183,1184,1185,1186,1187,1188,1189,1190,1191,1192,1193,1194,1195,1196,1197,1198,1199,1200,1201,1202,1203,1204,1205,1206,1207,1208,1209,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