维氏硬度基准、标准不确定度评估：

维氏基准：

一、力值变化引入的不确定度：

力值的变化会引起压痕长度的变化。力值每变化0.1%F，压痕长度变化0.05%*d*，标准不确定度为0.029%*d*。

二、压痕对角线测量引入的标准不确定度：

测量压痕对角线引入的不确定度分量为：

1、压痕测量装置：证书给出装置的扩展不确定度为:放大400×和200×时：*U*=0.4μm，放大100×时：*U*=0.5μm

2、人眼对线误差：

400×：$0.1（μm）$；

200×：$0.2（μm）$；

100×：$0.4（μm）$。

三、压头几何参数引入的不确定度：

1、压头棱面夹角：$\frac{u\_{α}}{2tg\frac{α}{2}}\frac{π}{180}$

压头棱面夹角：在0.1°范围内，变化非常小，可以忽略不计。4个基准压头，最大误差为0.1°。假设为均匀分布，则标准不确定度约为u*（α）*=0.06°，乘以灵敏系数得出：$\frac{u\_{(α)}}{2tg\frac{α}{2}}\frac{π}{180}$=0.02%

 2、压头顶端横刃：$\sqrt{2}×\frac{u\_{c}}{d}$

压头横刃：在0.4μm范围内，根据实验，维氏硬度值在中、高值范围影响量很小。

|  |  |  |
| --- | --- | --- |
| 硬度块编号 | 力值 | 压头编号 |
| UG7868 | UG8454 | UG8834 |
| 压头横刃尺寸 |
| 0.44μm | 2.15μm | 4.79μm |
| 压头棱面夹角 |
| 136°12′ | 135°46′ | 136°12′ |
| 136°03′ | 135°42′ | 136°07′ |
| 硬度值/HV | 硬度值/HV | 硬度值/HV |
| R6410-7640 | 5 | 474.8 | 479.0 | 477.7 |
| V657-121 | 5 | 444.7 | 444.1 | 445.0 |
| R6410-7640 | 10 | 473.0 | 474.9 | 473.6 |
| V657-121 | 10 | 442.7 | 443.1 | 443.4 |
| R6410-7640 | 30 | 472.9 | 473.4 | 472.8 |
| V657-121 | 30 | 445.2 | 446.3 | 445.9 |
| R6410-7640 | 50 | 474.4 | 473.8 | 475.2 |
| V657-121 | 50 | 446.6 | 447.5 | 448.2 |

一般认为，横刃尺寸大，压痕对角线尺寸会变小，维氏硬度值会大。也就是说，横刃尺寸大，硬度示值大。

UG7868、UG8834两个压头（绿色阴影）的夹角几乎相同。它们横刃却相差10倍，但对硬度值影响量却很小，它们测量同一个硬度块，示值却几乎相同。实验数据表明，压头横刃的几何尺寸在0.4μm范围内，对中、高硬度值的影响非常小，可以忽略不计。低硬度值部分，不一定。

横刃5次测量结果：0.4,0.3,0.4,0.3,0.4，平均值：0.4μm。

压痕有61μm—1005μm，横刃标准不确定度： 单位：μm

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 61 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1005 |
| 0.47% | 0.29% | 0.14% | 0.1% | 0.07% | 0.06% | 0.05% | 0.04% | 0.04% | 0.03% | 0.029% |

★维氏基准相对扩展不确定度：

$$U\_{rel}=2×\sqrt{(\left(-2\right)\left(\frac{u\_{d（F）}}{d}\right))^{2}+(\left(-2\right)\left(\frac{u\_{d1}}{d}\right))^{2}+(\left(-2\right)\left(\frac{u\_{d2}}{d}\right))^{2}+(\sqrt{2}×\frac{u\_{c}}{d})^{2}+(\frac{u\_{α}}{2tg\frac{α}{2}}\frac{π}{180})^{2}}$$

$u\_{d（F）}$:由力值变化引入的标准不确定度：（0.00029*d*）

$u\_{d1}$ ：由压痕测量装置引入的标准不确定度，根据证书

放大400×和200×时：*U*=0.4μm；

放大100×时：*U*=0.5μm。

$u\_{d2}$ ：由人眼误差引入的标准不确定度，

400×：*u*=0.1μm；200×：*u*=0.2μm；100×：*u*=0.4μm。

$u\_{α}$ ：压痕棱面夹角引入的标准不确定度，$\frac{u\_{α}}{2tg\frac{α}{2}}\frac{π}{180}$

$u\_{c}$ ：压头横刃引入的标准不确定度，$\sqrt{2}×\frac{u\_{c}}{d}$

400倍放大时：

$U\_{rel}$= 2$ ×\sqrt{0.0000003764+\frac{0.2841}{d^{2}}}$

200倍放大时：

$U\_{rel}$= 2$ ×\sqrt{0.0000003764+\frac{0.4041}{d^{2}}}$

100倍放大时：

$U\_{rel}$= 2$ ×\sqrt{0.0000003764+\frac{0.9741}{d^{2}}}$

维氏标准：

一、力值变化引入的不确定度：

力值的变化会引起压痕长度的变化。力值每变化0.1%F，压痕长度变化0.05%*d*，标准不确定度为0.029%*d*。

二、压痕对角线测量引入的标准不确定度：

测量压痕对角线引入的不确定度分量为：

1、压痕测量装置：JJG148-2006标准维氏硬度块检定规程规定最大允许误差为0.5%*d*，按均匀分布，的标准不确定度为0.29*d*%。

三、压头测量引入的不确定度：

1、压头棱面夹角：$\frac{u\_{α}}{2tg\frac{α}{2}}\frac{π}{180}$

压头棱面夹角：最大允许误差为0.1°。假设为均匀分布，则标准不确定度约为u*（α）*=0.06°，乘以灵敏系数得出：$\frac{u\_{(α)}}{2tg\frac{α}{2}}\frac{π}{180}$=0.02%

 2、压头顶端横刃：$\sqrt{2}×\frac{u\_{c}}{d}$

JJG148-2006标准维氏硬度块检定规程规定最大允许误差为1μm，按均匀分布，

横刃测量的标准不确定度为0.5774*μm*，×灵敏系数后，相对不确定度为$\sqrt{2}×\frac{u\_{c}}{d}=\frac{0.8166}{d}$。

★维氏标准相对扩展不确定度：

$U\_{rel}=2×\sqrt{(\left(-2\right)\left(\frac{u\_{d（F）}}{d}\right))^{2}+(\left(-2\right)\left(\frac{u\_{d1}}{d}\right))^{2}+(\sqrt{2}×\frac{u\_{c}}{d})^{2}+(\frac{u\_{α}}{2tg\frac{α}{2}}\frac{π}{180})^{2}}$ （ *k*=2）

$u\_{d（F）}$:由力值变化引入的标准不确定度；（0.00029*d*）

$u\_{d1}$ ：压痕测量装置：JJG148-2006规定最大允许误差为0.5%*d*。

$u\_{α}$ ：压痕棱面夹角引入的标准不确定度；$\frac{u\_{(α)}}{2tg\frac{α}{2}}\frac{π}{180}$=0.02%

$u\_{c}$ ：压头横刃引入的标准不确定度；$\sqrt{2}×\frac{u\_{c}}{d}=\frac{0.8166}{d}$

$$U\_{rel}=2×\sqrt{((-2)×0.00029)^{2}+((-2)×0.29\%)^{2}+(0.0002)^{2}+(\sqrt{2}×\frac{0.5774}{d})^{2}}$$

 =$2×\sqrt{0.000034+(\frac{0.8166}{d})^{2}}$

=$2×\sqrt{0.000034+\frac{0.6668}{d^{2}}}$

表1：维氏基准-维氏标准不确定度比较：

|  |  |
| --- | --- |
| 维氏硬度基准装置 | 维氏硬度标准装置 |
| $U\_{rel}$= 2$ ×\sqrt{0.0000003764+\frac{0.2841}{d^{2}}}$ （61-149）*μm*$U\_{rel}$= 2$ ×\sqrt{0.0000003764+\frac{0.4041}{d^{2}}}$ （152-534）*μm*$U\_{rel}$= 2$ ×\sqrt{0.0000003764+\frac{0.9741}{d^{2}}}$ （570-1005）*μm* | $$U\_{rel}=2×\sqrt{0.000034+\frac{0.6668}{d^{2}}}$$（61-1005）*μm* |
| 放大倍数 | 压痕长度 | 压痕测量装置标准不确定度*k*=2 | 维氏硬度值测量不确定度，*k*=2 | 压痕测量装置标准不确定度*k*=2 | 维氏硬度值测量不确定度，*k*=2 |
| 400× | 61μm | $U\_{rel}$=0.2*μm* | $U\_{rel}$=1.75% | 0.20*μm* | $U\_{rel}$=2.9% |
| 149μm | $U\_{rel}$=0.73% | 0.43*μm* | $U\_{rel}$=1.6% |
| 200× | 152μm | $U\_{rel}$=0.85% | 0.44*μm* | $U\_{rel}$=1.6% |
| 534μm | $U\_{rel}$=0.27% | 1.55*μm* | $U\_{rel}$=1.2% |
| 100× | 570μm | $U\_{rel}$=0.25*μm* | $U\_{rel}$=0.37% | 1.65*μm* | $U\_{rel}$=1.2% |
| 1005μm | $U\_{rel}$=0.23% | 2.91*μm* | $U\_{rel}$=1.2% |

★基准机不确定度及CMC能力：

表2 基准典型标尺典型硬度范围的测量不确定度以及校准和测量能力

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 放大倍率 | 相对扩展不确定度表达式，*k*=2 | 标尺及范围 | 相对扩展不确定度$U\_{rel}\left(H\right)(k=2)$,% | 校准和测量能力$U\left(H\right)(k=2)$，% |
| 400× | $U\_{rel}$= 2$ ×\sqrt{0.0000003764+\frac{0.2841}{d^{2}}}$（61-149）*μm* | (200~997)HV2**（136~61）μm** | 0.79%~1.75% | 1.0%~1.9% |
| (250~1000)HV3**（149~74.6）μm** | 0.73%~1.43% | 0.9%~1.5% |
| (440~1000)HV5**（145~96.3）μm** | 0.75%~1.11% | 0.9%~1.2% |
| (850~1000)HV10**（147~136.2）μm** | 0.74%~0.79% | 0.9%~1.0% |
| 200× | $U\_{rel}$= 2$ ×\sqrt{0.0000003764+\frac{0.4041}{d^{2}}}$（152-534）*μm* | (20~150)HV2**（431~157）μm** | 0.32%~0.82% | 0.6%~1.0% |
| (20~200)HV3**（528~167）μm** | 0.27%~0.77% | 0.6%~1.0% |
| (40~400)HV5**（482~152）μm** | 0.29%~0.85% | 0.6%~1.0% |
| (100~800)HV10**（430~152）μm** | 0.32%~0.85% | 0.6%~1.0% |
| (150~1000)HV20**（498~192.6）μm** | 0.28%~0.67% | 0.6%~0.9% |
| (200~1000)HV30**（528~236）μm** | 0.27%~0.55% | 0.6%~0.8% |
| (350~1000)HV50**（515~304.5）μm** | 0.28%~0.44% | 0.6%~0.7% |
| (650~1000)HV100**（534~431）μm** | 0.27%~0.32% | 0.6% |
| 100× | $U\_{rel}$= 2$ ×\sqrt{0.0000003764+\frac{0.9741}{d^{2}}}$（570-1005）*μm* | (5~10)HV2**（860~609）μm** | 0.26%~0.35% | 0.6%~0.7% |
| (5~10)HV3**（1005~746）μm** | 0.23%~0.29% | 0.6% |
| 28.5HV5**570μm** | 0.37% | 0.7% |
| (20~50)HV10**（963~609）μm** | 0.24%~0.35% | 0.6%~0.7% |
| (50~100)HV20**（861~609）μm** | 0.26%~0.35% | 0.6%~0.7% |
| (55~150)HV30**（1005~609）μm** | 0.23%~0.35% | 0.6%~0.7% |
| (100~300)HV50**（962~556）μm**(200~600)HV100 | 0.24%~0.38% | 0.6%~0.7% |
| 0.6%~0.7% |

### ★基准机定度比对维氏硬度块 / CMC能力

表3基准定度：典型标尺典型范围比对维氏硬度块的测量不确定度/CMC能力

均匀度要求为JJG148-2006中的一半

|  |  |  |  |
| --- | --- | --- | --- |
| 标尺及范围 | 压痕长度（*μm*） | 维氏基准 | 比对维氏块 |
| 相对扩展不确定度$U\_{rel}\left(H\right)(k=2)$,% | 相对扩展不确定度$U\_{rel}\left(H\right)(k=2)$,% |
| (175~225)HV2 | 145.6-128.4 | 0.74%-0.84% | 1.76%-1.81% |
| (400~600)HV2 | 96.3-78.6 | 1.11%-1.36% | 1.55%-1.74% |
| (700~800)HV2 | 72.8-68.1 | 1.47%-1.57% | 1.82%-1.91% |
| (175~225)HV3 | 178.3-157.2 | 0.72%-0.82% | 1.75%-1.80% |
| (400~600)HV3 | 117.9-96.3 | 0.91%-1.11% | 1.41%-1.55% |
| (700~800)HV3 | 89.1-83.4 | 1.20%-1.28% | 1.61%-1.67% |
| (175~225)HV5 | 230.2-203.0 | 0.57%-0.64% | 1.22%-1.26% |
| (400~600)HV5 | 152.2-124.3 | 0.71%-0.87% | 0.89%-1.02% |
| (700~800)HV5 | 115.1-107.6 | 0.93%-1.00% | 1.08%-1.14% |
| (175~225)HV10 | 325.5-287.1 |  0.41%-0.46% | 1.16%-1.17% |
| (400~600)HV10 | 215.3-175.8 | 0.60%-0.73% | 0.81%-0.91% |
| (700~800)HV10 | 162.8-152.2 | 0.79%-0.84% | 0.96%-1.00% |
| (175~225)HV20 | 460.3-406.0 | 0.30%-0.34% | 1.12%-1.13% |
| (400~600)HV20 | 304.5-248.6 | 0.44%-0.53% | 0.70%-0.76% |
| (700~800)HV20 | 230.2-215.3 | 0.57%-0.60% | 0.79%-0.81% |
| (175~225)HV30 | 563.8-497.2 | **0.37%**-0.28% | 1.14%-1.12% |
| (400~600)HV30 | 372.9-304.5 | 0.36%-0.44% | 0.65%-0.70% |
| (700~800)HV30 | 281.9-263.7 | 0.47%-0.50% | 0.72%-0.74% |
| (175~225)HV50 | 727.9-641.9 | 0.30%-0.33% | 1.12%-1.13% |
| (400~600)HV50 | 481.4-393.1 | 0.29%-0.35% | 0.61%-0.64% |
| (700~800)HV50 | 363.9-340.4 | 0.37%-0.39% | 0.65%-0.67% |
| (200~225)HV100 | 962.0-907.8 | 0.24%-0.25% | 1.11% |
| (400~600)HV100 | 680.9-555.9 | 0.31%-0.38% | 0.62%-0.66% |
| (700~800)HV100 | 514.7-481.4 | 0.28%-0.29% | 0.61% |

★基准机定度标准维氏硬度块

表4基准定度：典型标尺典型范围标准维氏硬度块的测量不确定度

|  |  |  |  |
| --- | --- | --- | --- |
| 标尺及范围 | 压痕长度（*μm*） | 维氏基准 | 一等标准维氏块 |
| 相对扩展不确定度$U\_{rel}\left(H\right)(k=2)$,% | 相对扩展不确定度$U\_{rel}\left(H\right)(k=2)$,% |
| (175~225)HV2 | 145.6-128.4 | 0.74%-0.84% | 3.30%-3.33% |
| (400~600)HV2 | 96.3-78.6 | 1.11%-1.36% | 2.41%-2.54% |
| (700~800)HV2 | 72.8-68.1 | 1.47%-1.57% | 2.60%-2.65% |
| (175~225)HV3 | 178.3-157.2 | 0.72%-0.82% | 3.30%-3.32% |
| (400~600)HV3 | 117.9-96.3 | 0.91%-1.11% | 2.33%-2.41% |
| (700~800)HV3 | 89.1-83.4 | 1.20%-1.28% | 2.45%-2.49% |
| (175~225)HV5 | 230.2-203.0 | 0.57%-0.64% | 2.21%-2.23% |
| (400~600)HV5 | 152.2-124.3 | 0.71%-0.87% | 1.29%-1.39% |
| (700~800)HV5 | 115.1-107.6 | 0.93%-1.00% | 1.43%-1.47% |
| (175~225)HV10 | 325.5-287.1 |  0.41%-0.46% | 2.18%-2.19% |
| (400~600)HV10 | 215.3-175.8 | 0.60%-0.73% | 1.24%-1.30% |
| (700~800)HV10 | 162.8-152.2 | 0.79%-0.84% | 1.34%-1.37% |
| (175~225)HV20 | 460.3-406.0 | 0.30%-0.34% | 2.16%-2.17% |
| (400~600)HV20 | 304.5-248.6 | 0.44%-0.53% | 1.17%-1.20% |
| (700~800)HV20 | 230.2-215.3 | 0.57%-0.60% | 1.22%-1.24% |
| (175~225)HV30 | 563.8-497.2 | **0.37%**-0.28% | 2.17%-2.16% |
| (400~600)HV30 | 372.9-304.5 | 0.36%-0.44% | 1.14%-1.17% |
| (700~800)HV30 | 281.9-263.7 | 0.47%-0.50% | 1.18%-1.19% |
| (175~225)HV50 | 727.9-641.9 | 0.30%-0.33% | 2.16%-2.17% |
| (400~600)HV50 | 481.4-393.1 | 0.29%-0.35% | 1.12%-1.14% |
| (700~800)HV50 | 363.9-340.4 | 0.37%-0.39% | 1.14%-1.15% |
| (200~225)HV100 | 962.0-907.8 | 0.24%-0.25% | 2.15% |
| (400~600)HV100 | 680.9-555.9 | 0.31%-0.38% | 1.12%-1.14% |
| (700~800)HV100 | 514.7-481.4 | 0.28%-0.29% | 1.12% |

### ★标准维氏硬度机的相对扩展不确定度为(1.18-2.67)%,*k*=2。

表5 标准维氏硬度机典型标尺典型范围的测量不确定度

|  |  |  |  |
| --- | --- | --- | --- |
| 相对扩展不确定度表达式，*k*=2 | 标尺及范围 | 压痕长度（*μm*） | 相对扩展不确定度$U\_{rel}\left(H\right)(k=2)$,% |
| $$U\_{rel}=2×\sqrt{0.000034+\frac{0.6668}{d^{2}}}$$ | (175~225)HV2 | 145.6-128.4 | 1.62%-1.73% |
| (400~600)HV2 | 96.3-78.6 | 2.06%-2.38% |
| (700~800)HV2 | 72.8-68.1 | 2.53%-2.67% |
| (175~225)HV3 | 178.3-157.2 | 1.48%-1.56% |
| (400~600)HV3 | 117.9-96.3 | 1.81%-2.06% |
| (700~800)HV3 | 89.1-83.4 | 2.17%-2.28% |
| (175~225)HV5 | 230.2-203.0 | 1.37%-1.42% |
| (400~600)HV5 | 152.2-124.3 | 1.58%-1.76% |
| (700~800)HV5 | 115.1-107.6 | 1.84%-1.91% |
| (175~225)HV10 | 325.5-287.1 | 1.27%-1.30% |
| (400~600)HV10 | 215.3-175.8 | 1.39%-1.49% |
| (700~800)HV10 | 162.8-152.2 | 1.54%-1.58% |
| (175~225)HV20 | 460.3-406.0 | 1.22%-1.23% |
| (400~600)HV20 | 304.5-248.6 | 1.28%-1.34% |
| (700~800)HV20 | 230.2-215.3 | 1.37%-1.39% |
| (175~225)HV30 | 563.8-497.2 | 1.20%-1.21% |
| (400~600)HV30 | 372.9-304.5 | 1.25%-1.28% |
| (700~800)HV30 | 281.9-263.7 | 1.30%-1.32% |
| (175~225)HV50 | 727.9-641.9 | 1.19% |
| (400~600)HV50 | 481.4-393.1 | 1.21%-1.24% |
| (700~800)HV50 | 363.9-340.4 | 1.25%-1.26% |
| (200~225)HV100 | 962.0-907.8 | 1.18% |
| (400~600)HV100 | 680.9-555.9 | 1.19%-1.20% |
| (700~800)HV100 | 514.7-481.4 | 1.21% |

##

### ★标准维氏硬度机定度标准维氏硬度块，按照JJG148-2006进行定度。

表6 典型标尺典型范围标准维氏硬度块的测量不确定度

|  |  |  |  |
| --- | --- | --- | --- |
| 标尺及范围 | 压痕长度（*μm*） | 维氏标准 | 二等标准维氏块 |
| 相对扩展不确定度$U\_{rel}\left(H\right)(k=2)$,% | 相对扩展不确定度$U\_{rel}\left(H\right)(k=2)$,% |
| (175~225)HV2 | 145.6-128.4 | 1.62%-1.73% | 3.60%-3.66% |
| (400~600)HV2 | 96.3-78.6 | 2.06%-2.38% | 2.97%-3.20% |
| (700~800)HV2 | 72.8-68.1 | 2.53%-2.67% | 3.31%-3.42% |
| (175~225)HV3 | 178.3-157.2 | 1.48%-1.56% | 3.54%-3.58% |
| (400~600)HV3 | 117.9-96.3 | 1.81%-2.06% | 2.80%-2.97% |
| (700~800)HV3 | 89.1-83.4 | 2.17%-2.28% | 3.05%-3.13% |
| (175~225)HV5 | 230.2-203.0 | 1.37%-1.42% | 1.74%-1.78% |
| (400~600)HV5 | 152.2-124.3 | 1.58%-1.76% | 2.66%-2.77% |
| (700~800)HV5 | 115.1-107.6 | 1.84%-1.91% | 2.82%-2.87% |
| (175~225)HV10 | 325.5-287.1 | 1.27%-1.30% | 1.67%-1.69% |
| (400~600)HV10 | 215.3-175.8 | 1.39%-1.49% | 1.76%-1.84% |
| (700~800)HV10 | 162.8-152.2 | 1.54%-1.58% | 1.88%-1.91% |
| (175~225)HV20 | 460.3-406.0 | 1.22%-1.23% | 1.63%-1.64% |
| (400~600)HV20 | 304.5-248.6 | 1.28%-1.34% | 1.67%-1.72% |
| (700~800)HV20 | 230.2-215.3 | 1.37%-1.39% | 1.74%-1.76% |
| (175~225)HV30 | 563.8-497.2 | 1.20%-1.21% | 1.61%-1.62% |
| (400~600)HV30 | 372.9-304.5 | 1.25%-1.28% | 1.65%-1.67% |
| (700~800)HV30 | 281.9-263.7 | 1.30%-1.32% | 1.69%-1.71% |
| (175~225)HV50 | 727.9-641.9 | 1.19% | 1.61% |
| (400~600)HV50 | 481.4-393.1 | 1.21%-1.24% | 1.62%-1.64% |
| (700~800)HV50 | 363.9-340.4 | 1.25%-1.26% | 1.65%-1.66% |
| (200~225)HV100 | 962.0-907.8 | 1.18% | 1.60% |
| (400~600)HV100 | 680.9-555.9 | 1.19%-1.20% | 1.61% |
| (700~800)HV100 | 514.7-481.4 | 1.21% | 1.62% |