✅ 优化完成! 最佳平均验证准确率 (来自Optuna): 52.791%

最佳参数: {'lr': 3.877108020770023e-05, 'batch\_size': 16, 'dropout': 0.48844724731296935, 'weight\_decay': 4.828633474105562e-05, 'optimizer': 'AdamW', 'max\_grad\_norm': 1.2051110848676112, 'use\_focal': True, 'use\_ls': False, 'use\_center': False, 'focal\_alpha': 0.37280522544816064, 'focal\_gamma': 1.3564046794782432}

✅ 最佳超参数已保存至: ./hyperparameter\_optimization\_20251027\_002422\best\_params.json

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🚀 开始训练最终 5-Fold 集成模型...

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--- 正在训练 Fold 1/5 ---

Fold 0 归一化统计数据已保存。

Epoch 20/100, Val Loss: 0.3237, Val Acc: 46.51%

Epoch 40/100, Val Loss: 0.3074, Val Acc: 48.26%

Epoch 60/100, Val Loss: 0.3111, Val Acc: 49.42%

Epoch 80/100, Val Loss: 0.3118, Val Acc: 48.84%

Epoch 100/100, Val Loss: 0.3121, Val Acc: 47.67%

Fold 0 训练完毕。最佳验证准确率: 50.581%

Fold 0 最佳模型已保存。

--- 正在训练 Fold 2/5 ---

Fold 1 归一化统计数据已保存。

Epoch 20/100, Val Loss: 0.3195, Val Acc: 52.33%

Epoch 40/100, Val Loss: 0.2927, Val Acc: 49.42%

Epoch 60/100, Val Loss: 0.2949, Val Acc: 48.26%

Epoch 80/100, Val Loss: 0.2960, Val Acc: 48.84%

Epoch 100/100, Val Loss: 0.2969, Val Acc: 48.26%

Fold 1 训练完毕。最佳验证准确率: 53.488%

Fold 1 最佳模型已保存。

--- 正在训练 Fold 3/5 ---

Fold 2 归一化统计数据已保存。

Epoch 20/100, Val Loss: 0.3350, Val Acc: 41.28%

Epoch 40/100, Val Loss: 0.3277, Val Acc: 44.19%

Epoch 60/100, Val Loss: 0.3359, Val Acc: 43.60%

Epoch 80/100, Val Loss: 0.3393, Val Acc: 43.02%

Epoch 100/100, Val Loss: 0.3406, Val Acc: 43.02%

Fold 2 训练完毕。最佳验证准确率: 47.093%

Fold 2 最佳模型已保存。

--- 正在训练 Fold 4/5 ---

Fold 3 归一化统计数据已保存。

Epoch 20/100, Val Loss: 0.3301, Val Acc: 48.26%

Epoch 40/100, Val Loss: 0.3254, Val Acc: 45.93%

Epoch 60/100, Val Loss: 0.3294, Val Acc: 46.51%

Epoch 80/100, Val Loss: 0.3306, Val Acc: 48.26%

Epoch 100/100, Val Loss: 0.3320, Val Acc: 48.26%

Fold 3 训练完毕。最佳验证准确率: 52.907%

Fold 3 最佳模型已保存。

--- 正在训练 Fold 5/5 ---

Fold 4 归一化统计数据已保存。

Epoch 20/100, Val Loss: 0.3161, Val Acc: 46.51%

Epoch 40/100, Val Loss: 0.3016, Val Acc: 49.42%

Epoch 60/100, Val Loss: 0.3097, Val Acc: 48.26%

Epoch 80/100, Val Loss: 0.3139, Val Acc: 48.84%

Epoch 100/100, Val Loss: 0.3152, Val Acc: 48.84%

Fold 4 训练完毕。最佳验证准确率: 52.326%

Fold 4 最佳模型已保存。

✅ 5-Fold 集成模型训练完毕。

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📊 5-Fold 集成模型在 [纯净验证集] 上的聚合性能报告

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--- 详细性能报告 ---

--- 整体宏平均指标 ---

总体准确率 (Accuracy): 0.513

宏平均F1分数 (Macro-F1): 0.533

宏平均精确率 (Macro-Precision): 0.535

宏平均召回率 (Macro-Recall): 0.534

--- 各类别详细指标 (Precision, Recall, F1-Score) ---

precision recall f1-score support

inner\_broken 0.347 0.273 0.306 150

inner\_wear 0.505 0.433 0.466 120

normal 0.494 0.531 0.512 160

outer\_missing 0.507 0.594 0.547 180

roller\_broken 0.359 0.373 0.366 150

roller\_wear 1.000 1.000 1.000 100

accuracy 0.513 860

macro avg 0.535 0.534 0.533 860

weighted avg 0.508 0.513 0.508 860

--- 混淆矩阵 ---

类别索引: {'inner\_broken': 0, 'inner\_wear': 1, 'normal': 2, 'outer\_missing': 3, 'roller\_broken': 4, 'roller\_wear': 5}

矩阵 (行: 真实标签, 列: 预测标签):

[[ 41 14 24 40 31 0]

[ 14 52 11 30 13 0]

[ 16 9 85 12 38 0]

[ 25 17 13 107 18 0]

[ 22 11 39 22 56 0]

[ 0 0 0 0 0 100]]

