Experimental studying of the crack resistance for the CuAl9Mn2 alloy during growing of samples by the method of laser powder surfacing

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Abstract. The paper presents the results of experimental studies of crack resistance at the fusion boundary of the base material and the built-up layer in cylindrical specimens made of CuAl9Mn2 alloy using additive technology of powder laser surfacing. The aim of the study is to analyze possible changes in the mechanical properties of the base material at the fusion boundary under the action of high temperatures. On the basis of the experimental data it is obtained that the thermal action during laser powder surfacing has not a great impact on the crack resistance of both the base material and the built-up metal.

1. Introduction
Laser powder surfacing is one of the most advanced additive technologies for the manufacturing and revitalization of elements and structures [1 – 3]. The use of high-power industrial lasers leads to local exposure of high temperatures. Such an effect can cause various changes (including negative ones) in the structure and mechanical properties of the material [4, 5]. The paper presents the results of an experimental study of possible changes in the crack resistance [6, 7] which is one of the most important characteristics of structural materials and significantly affects on the reliability of a structure. The main aim of our work is to investigate the influence of thermal effects during surfacing on the properties of the base material and the behaviour of a directional crack when it meets the melting boundary.

2. Determination of $K_{IC}$
In work we use the critical stress intensity factor $K_{IC}$ [6, 7] as a main characteristic for crack resistance of material. The actual value of $K_{IC}$ is calculated due to [6] for different samples:

$$K_{IC} = \frac{0.7976 \mu h F \sqrt{D}}{(1-v)L},$$

where $F = \frac{1 - \varepsilon (1 + \varepsilon^{-1})^2}{\sqrt{\varepsilon^{-1} - 0.8212}} \left[ \sqrt{\varepsilon^{-1} - 1 + \sqrt{16 L (3\pi D (1 - v^2))^{-1}}} \right]^{-2}$, $\varepsilon = d / D$,

$\mu$ = Shear modulus,
$v$ = Poisson ratio,
$\varepsilon$ = Dimensionless parameter,
$L$ = 0.5 Length of specimen,
\( d \) = Isthmus diameter of specimen,
\( D \) = External diameter of specimen,
\( h \) = Beam deflection (defined experimentally at the critical load \( P^* \) according with the crack initiation during a linear stage).

3. Materials and Methods

3.1 Material

For investigation we used the CuAl9Mn2 alloy (aluminum bronze) in solid and powder forms. The chemical composition [8] is shown in Table 1.

|      | Al | Mn | Sn | Si | Pb | P  | Fe | Zn | Cu   |
|------|----|----|----|----|----|----|----|----|------|
| min  | 8.0| 1.5| –  | –  | –  | –  | –  | –  | Balance |
| max  | 10.0| 2.5| 0.1| 0.1| 0.03| 0.01| 0.5| 1.0|      |

3.2 Specimen preparation

We conducted an experiment on two groups of cylindrical specimens (the schematic of specimen geometry with a length \( 2L \) of 100 mm and a diameter \( D \) of 10 mm is presented on the figure 1). The reference group of specimens was made from a CuAl9Mn2 solid cylindrical bar. When manufacturing of grown specimens, a CuAl9Mn2 powder was fused on a cylindrical aluminum bronze core with a diameter \( d_0 \) of 6 mm by using a laser surfacing method. On each specimen, a V-groove of \( \alpha = 30^\circ \) has been cut to a depth \( H \) of 0.75 mm circumferentially in the center of the bar (figure 1, area A). Then, at the root of V-notch, an initiating sickle-shaped fatigue crack \( C \) has been grown without intersecting the boundary of the main material and the melting layer (figure 1, cross-section B-B; \( D-2H<d<D-d_0 \)).
3.3 Experimentation

The figure 2 shows a few specimens before testing. Totally six specimens were prepared: three reference samples and three grown ones. The specimens were tested under three-point bending by using SHIMADZU AGS–10kNXD (figure 3). The load $P$ was applied for the stress raiser area (circular groove). The Crack Mouth Opening Displacement (CMOD) at the crack initiation and corresponding value of a beam deflection were targeted experimental parameters. The CMOD was measured by using a Double-Cantilever Clip-in Displacement Gage. The figure 4 presents the cross-view of the specimen No 3 after testing.

![Figure 2. The specimens No 4–6 before testing](image1)

![Figure 3. Mechanical test equipment SHIMADZU AGS–10kNXD](image2)

![Figure 4. The magnified cross-view of the specimen No 3 after fracture](image3)
4. Results and Discussion

For all prepared samples, the test results were obtained in a graphical form by using the equipment described above. Figure 5 presents the diagrams with results of mechanical test by three-point bending for reference sample No 3. Figure 6 shows the diagrams obtained for grown sample No 4. On the left diagrams (figures 5a and 6a) the experimental curves “load $P$ – crack mouth opening displacement $a$” are shown. The right diagrams (figures 5b and 6b) are the experimental curves “load $P$ – beam deflection $h$”. From the “$P$–$a$” diagram we get the critical value of the load $P^*$, at which the crack mouth opening displacement $a$ begins to grow rapidly. Then, from the “$P$–$h$” diagram, we find the corresponding value $h^*(P^*)$ for the beam deflection used to calculate $K_{IC}$.

![Figure 5. Test diagrams for reference specimen No 3 ($a^*=0.74$ mm, $P^*=3.0$ kN, $h^*=3.2$ mm)](image)

![Figure 6. Test diagrams for grown specimen No 4 ($a^*=0.49$ mm, $P^*=2.0$ kN, $h^*=2.4$ mm)](image)
Table 2 presents the summary results of testing. The critical stress intensity factor $K_{IC}$ is calculated due to the formula (1) on basis experimental data obtained. Its average values $\bar{K}_{IC}$ for reference specimens No 1–3 and grown specimens No 4–6 are very close (mismatch < 5%).

| S. No | $D$ (mm) | $d$ (mm) | $L$ (mm) | $h$ (mm) | $\varepsilon$ | $K_{IC}$ (MPa m$^{1/2}$) | Average value $\bar{K}_{IC}$ (MPa m$^{1/2}$) |
|-------|----------|----------|----------|----------|--------------|-----------------|-------------------------|
| 1     | 10,000   | 9,150    | 92,000   | 2,800    | 0,915        | 67,64590        | 75,12007                |
| 2     | 10,000   | 9,050    | 92,000   | 2,900    | 0,905        | 72,54540        | 74,950267               |
| 3     | 10,000   | 8,830    | 92,000   | 3,200    | 0,883        | 85,16890        |                         |
| 4     | 10,000   | 8,850    | 90,000   | 2,400    | 0,885        | 66,25360        |                         |
| 5     | 10,000   | 9,040    | 82,000   | 2,690    | 0,904        | 83,96660        | 74,63060                |
| 6     | 10,000   | 8,800    | 88,000   | 2,560    | 0,880        | 74,63060        |                         |

5. Conclusion
Thus, based on the test results for the CuAl9Mn2 alloy, we can conclude that the thermal effect on the structural material during laser powder surfacing does not significantly affect the crack resistance characteristics of the base material.

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