Introduction

Welding tasks in gear manufacturing include diameters up to 250 mm and cross sections up to 1500 mm². Capacitor-discharge welding is a highly dynamic process in which the entire weld seam cross section is produced simultaneously in less than 40 ms by a high-current pulse of several hundred kiloamperes. Annular seams can be produced by at least one of the joining partners having an annular projection contour for the current density concentration needed. The simultaneously welding of the cross section and short welding times favor a low thermal distortion. The fast welding process runs event-driven, an intervention is not possible. This means that the welding result is already determined by the predefined input parameters at the start of the process.

Basis of Capacitor-Discharge-Welding (CD-welding)

- Resistance pressure welding process, Joule resistance heating of the joint.
- Main field of application is projection welding.
- Energy supply through a capacitor-discharge.
- High pulsed welding currents up to 1000 kA.
- Extremely short welding times (~1 - 40 ms)

Joule heating:

\[ \dot{q} = \frac{Q}{A_L} = j^2 \cdot R \]

- Heat flux density
- Current density
- Ohmic resistance
- Heat flux
- Conductive cross section

CD-welding of annular axial seams

- An oversize \( x \) on at least one part is used as projection geometry.
- The contact geometry before welding can be described with the oversize \( x \), the contact angle \( \alpha \) and the resulting contact width \( w \).
- Under pressure and heating, the parts sink into each other by the melt distance \( s \), that is directly related to the achieved bond width.

Problem statement and objective of the investigation

- For a high possible load-bearing capacity, large bond widths are required between the joining partners in car transmission constructions.
- In CD-welding, only a certain amount of energy can be supplied into the process and a certain bond width can be achieved before weld spatters occur, which is not permissible.

The aim of the study is therefore to investigate the influence of various input parameters on the achievable bond width before macroscopic weld spatters occur.

Influence of the oversize \( x \)

- Achievable bond width for different oversizes \( x \) is studied.
- First, the actual average size of each oversize \( x_1 \) - \( x_p \) (shaft) and the actual diameter of the hub \( D_{hub} \) (10 samples from each geometry) was measured:
  \[ x_1 = 0.351 \text{ mm}, \quad x_2 = 0.448 \text{ mm}, \quad x_p = 0.546 \text{ mm}, \quad D_{hub} = 53.987 \text{ mm}. \]
- Welding conditions: electrode force \( F \approx 60 \text{ kN} \), current rise time \( t_p \approx 11.3 \text{ ms} \), repositioning stiffness \( k \approx 8.5 \text{ kN/mm} \).

Influence of the current rise time \( t_p \)

- For higher charging energies \( E \) the peak current \( i_p \) rises, but weld times stay constant.
- Achievable bond width for different current rise times \( t_p \) is studied.
- Configurations:
  - \( t_p = 5.3 \text{ ms} (E= 8 \text{ MJ}, i_p = 1:120), t_p = 8.8 \text{ ms} (E= 24 \text{ MJ}, i_p = 1:120), t_p = 11.3 \text{ ms} (E= 24 \text{ MJ}, i_p = 1:160), t_p = 15.6 \text{ ms} (E= 24 \text{ MJ}, i_p = 1:240). \)
- Welding conditions: electrode force \( F \approx 60 \text{ kN}, \) oversize \( x \approx 0.45 \text{ mm}, \) repositioning stiffness \( k \approx 8.5 \text{ kN/mm} \).

Influence of the spring stiffness \( k \) (repositioning unit)

- Achievable bond width for four different spring stiffness \( k \) is studied.
- Two spiral spring packages (linear) and two elastomer spring packages (progressive).
- Spiral spring package 1: \( k = 8.5 \text{ kN/mm} \), Spiral spring package 2: \( k = 18.7 \text{ kN/mm} \).
- Elastomer spring package 1: \( k = 3 \text{ kN/mm} \), elastomer spring package 2: \( k = 10 \text{kN/mm} \).
- Welding conditions: current rise time \( t_p \approx 11.3 \text{ ms}, \) oversize \( x \approx 0.45 \text{ mm}, \) electrode force \( F \approx 60 \text{ kN}. \)

Summary

- All four investigated parameters (oversize \( x \), current rise time \( t_p \), electrode force \( F \) and spring stiffness \( k \)) have a decisive influence on the achievable bond width.
- In particular, short current rise times \( t_p \) and low electrode forces \( F \) lead to a premature weld splatter formation and therefore severely restrict the achievable bond width.
- For the studied diameter of 54 mm to be welded, melt distances \( s \) (and therefore bond widths) of up to 3 mm could be achieved without weld splatter formation occurring.

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