

Influencing Factors on the Strength of Electromagnetically Produced Form-Fit Joints using Knurled Surfaces^{*}

C. Weddeling¹, S. Gies¹, J. Nellesen², L. Kwiatkowski¹,
W. Tillmann², A. E. Tekkaya¹

¹ Institute of Forming Technology and Lightweight Construction, TU Dortmund University, Dortmund, Germany

² Institute of Materials Engineering, TU Dortmund University, Dortmund, Germany

Abstract

Joining by electromagnetic forming is a non-contact assembling method that is especially suitable for connections in aluminum space frame structures. By reason of increased joint strength along with lower charging energies, form-fit connections are favored over interference-fit connections for this joining process. In contrast to conventional form-fit concepts, in which the inner joining partner has grooves or pockets, the use of knurled surfaces offers several advantages like easier machinability or the resistance against combined axial and torsional loadings. The objective of this paper is to identify the influencing geometry and process parameters on the joint strength of tubular joints using mandrels with knurled surfaces, with tube and mandrel being made of the same aluminum alloy AA6060-T6. For that reason, experimental studies were conducted: In addition to pull-out tests to determine the axial strength of joints, first computed tomographic images and, afterwards, micrographs of joined components were produced to analyze the contact zone between tube and mandrel and the deformation behavior of the inner joining partner by non-destructive and destructive means. Based on the detailed knowledge of the influencing variables, guidelines for joint and process design are derived.

Keywords

Lightweight frame structures, Joining by electromagnetic forming, Form-fit joints

^{*} This paper is based on investigations of the Collaborative Research Center SFB/TR10 subproject A10 "Joining by Forming" which is kindly supported by the German Research Foundation (DFG). The high-performance microfocus computertomography system used in this work could be purchased in the scope of the DFG project INST 212/209-1 FUGG, which is gratefully acknowledged as well.

1 Introduction

To reconcile the increasing pursuit of individual mobility in modern societies [1] with the efforts in environmental protection in terms of strict emission standards, innovative vehicle concepts are required. No matter whether these concepts are based on fuel-efficient combustion engines or electric powertrains, they mainly depend on lightweight constructions to achieve a reduction of the car's total weight [2]. Space frame structures made of extruded aluminum profiles are a promising approach to reach this aim. The high rigidity in relation to their weight as well as the nearly unlimited variety of profile geometries are inherent advantages of this technology [3, 4]. However, the production of high-strength joints still remains one of the most challenging problems within the manufacturing process of suchlike aluminum structures. Joining by electromagnetic forming is an alternative to conventional thermal and mechanical joining technologies. It does not require any additional joining elements, and microstructural transformations, that might be caused by excessive heat input during welding operations, do not occur.

2 State of the Art

Electromagnetic forming (EMF) also known as Electromagnetic Pulse Forming Technology (EMPT) is a non-contact forming process using pulsed magnetic fields to create the required forces for workpiece deformation [5]. As these forces increase with rising electrical conductivity of the workpiece, especially copper and aluminum are suitable materials for this forming process. Depending on geometry and positioning of workpiece and tool coil, the process can either be used for expansion or compression of profiles with closed cross section or for sheet metal forming. The experimental setup for tube compression is shown in Figure 1 while the following explanation of the working mechanism is valid for the other process variants in analogous manner, too.

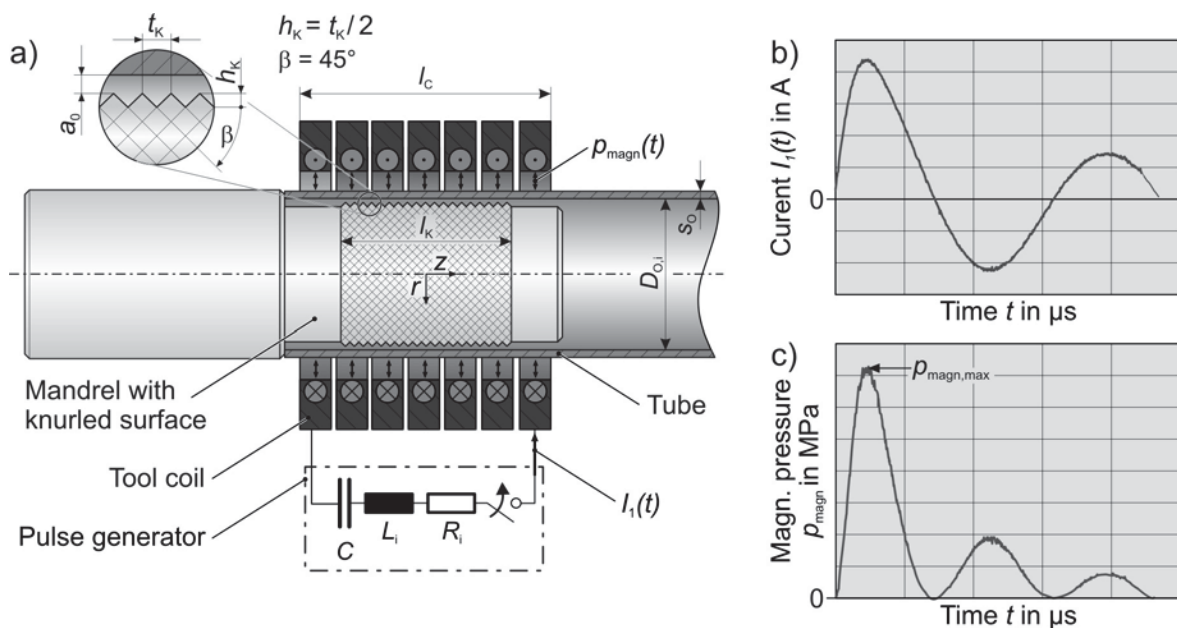


Figure 1: Process mechanism of electromagnetic tube compression

The setup for electromagnetic forming basically consists of the magnetic pulse generator, the tool coil and the workpiece to be deformed [6]. The pulse generator can be described as an oscillating circuit characterized by its capacity C , the inductance L_i and the resistance R_i . The forming process is initiated by closing the high current switch of the pulse generator leading to a sudden discharge of the energy stored in the capacitor C . This discharge causes a damped sinusoidal current $I_1(t)$ (see Figure 1b) running through the windings of the tool coil, that generates a time- and position-dependent magnetic field $H(r,z,t)$ between tool coil and workpiece. This magnetic field induces an eddy current into the workpiece whose direction is opposed to the coil current $I_1(t)$. In consequence of the opposing current flows, a repulsive force is generated between workpiece and tool coil. If the stresses inside the workpiece caused by this repulsive force exceed the yield strength of the workpiece material, plastic deformation of the tube occurs [5].

2.1 Joining by Electromagnetic Forming

The working mechanism of the electromagnetic forming process described above can be used for forming, cutting and joining purposes, whereas the latter is the main field of application for this technology [7]. Depending on the dominating locking mechanism, joints produced by electromagnetic forming can be classified into form-fit joints, interference-fit joints and joints based on metallic bonding [8]. In case of interference-fit joints an interference pressure between the inner and the outer joining partner is generated as the complete elastic springback of the elastically deformed joining partner is restrained due to the plastic deformation of the other joining partner [9]. Metallic bonding between the joining partners is generated if the impact velocity is high enough, leading to the formation of interatomic forces between the colliding surfaces. Form-fit joints are based on normal forces between interlocking surfaces. Hence, one joining partner has to be equipped with grooves, pockets or any other indentations, that can be used to form an undercut. Investigations on the effect of circumferential grooves in tubular joints [8, 10, 11, 12] demonstrated the effectiveness of such geometric elements to increase the axial joint strength in comparison to dominant interference-fit connections. However, these investigations also revealed crucial disadvantages of this concept. These include material thinning due to the large amount of plastic deformation to reach a filling of the groove as well as necking and shearing of the tube material at the grooves edges [8]. An alternative interlock mechanism to avoid these disadvantages are surfaces with a knurled structure (see Figure 1a). Additionally, this concept leads to a simultaneous increase of axial and torsional connection strength.

Eguia et al. [13] investigated the influence of knurled surfaces on the axial strength of electromagnetically crimped tubular joints. The outer joining partner, made of the aluminum alloy AA6061-T6, had an outer diameter of 28.5 mm and a wall thickness of 1.47 mm. Massive mandrels made of low carbon steel were used as inner joining partner, whose surface was structured with a cross knurl pattern. Within their joining experiments Eguia et al. not only varied the knurling pitch t_k but also the length of the knurling zone l_k , the charging energy E_C as well as the initial gap a_0 between tube and mandrel (see Figure 1a). The determination of the connection strength revealed that a fine knurl leads to higher axial strengths than a knurling pattern with a coarse pitch. As expected, an increasing knurling length results in rising joint strength whereas strength and knurling length did not correlate in a proportional manner. A doubling of the knurling length l_k increased the joint

strength by approximately 25 %. Furthermore, variations of charging energy and initial gap proved that the connection strength is substantially influenced by the impact velocity between tube and mandrel in case of constant knurling length and pitch.

In [14] Marré et al. developed a joining strategy for high strength joints between a massive aluminum mandrel and a continuously reinforced aluminum profile. Conventional form-fit concepts using grooves or pockets were not applicable in case of reinforced profiles as the required amount of deformation would cause delamination or necking of the reinforcing elements. A dominating interference-fit connection was not suitable because of the limited connection strength. Thus, the surface of the inner joining partner was cross knurled to reach a high connection strength without exceeding the tolerable amount of deformation. In this way, connection strengths of approximately 70 kN could be achieved, which is an increase of 75% compared to a dominating interference-fit connection. This increase was attributed to the increasing contact surface between tube and mandrel and the indentation of the knurling teeth into the surface of the outer joining partner.

3 Motivation

The above mentioned investigations proved the effectiveness of knurled surfaces as interlocking elements. As the investigation performed by Marré et al. [14] was a mere feasibility study, the effect of different process, geometry or material parameters was not analyzed further. Moreover, it is doubtful whether the results generated by Eguia et al. [13] are valid for the case that both joining partners are produced of aluminum.

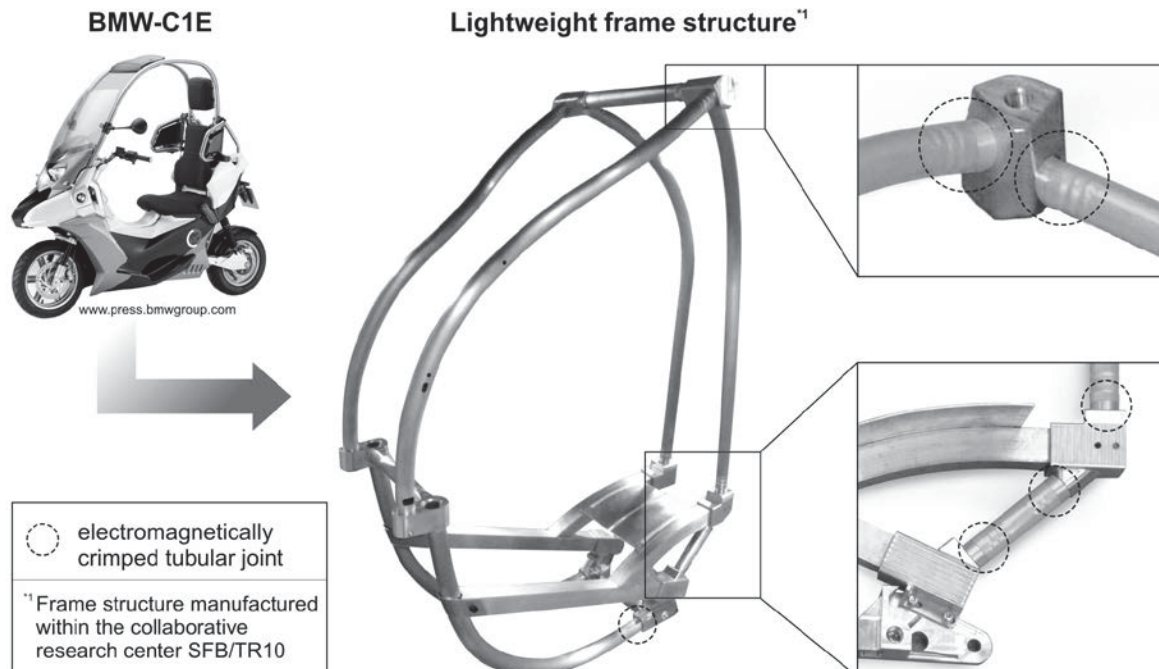


Figure 2: Aluminum spaceframe structure with electromagnetically crimped tubular joints

For this reason, additional experimental research was performed using tubes and mandrels made of the same aluminum alloy. Based on the results, recommendations for

process and joint design will be derived. The spaceframe structure depicted in Figure 2 may be cited as an example for a lightweight construction with suchlike tubular joints.

4 Experimental Procedure

Following the experimental design of Eguia et al. [13], knurling pitch t_k , knurling length l_k , charging energy E_c and initial gap a_0 were varied. Additionally, for reason of weight reduction, the effect of different mandrel stiffnesses was investigated using hollow mandrels with varying inner diameter. Both joining partners were produced of the same aluminum alloy AA6060-T6. In this way, the amount of interference fit was decreased [8] so that the resulting joint strength could be mainly attributed to the form fit caused by the knurled surface. The tube had an outer diameter of $D_{o,i} = 40$ mm and a wall thickness of $s_o = 2$ mm. The surface of the mandrel was structured with a cross knurl pattern according to DIN 82 as depicted in Figure 1a. Figure 3 summarizes all investigated combinations of the geometry and process parameters. Additionally interference-fit connections were produced using mandrels with a smooth surface.

| | initial gap a_0 [mm] | | | | energy E_c [kJ] | | | knurling length l_k [mm] | | | mandrel type | |
|--|------------------------|---|---|-----|-------------------|-----|-----|----------------------------|----|----|--------------|--------|
| knurling pitch | 0 | 1 | 2 | 2,5 | 4.8 | 6.0 | 7.2 | 20 | 40 | 60 | massive | hollow |
| $t_k = 0.5$ mm | X | X | X | X | X | X | X | | | X | X | |
| $t_k = 1.0$ mm | X | X | X | X | X | X | X | | | X | X | |
| $t_k = 1.0$ mm | X | X | X | X | | | X | X | X | | X | |
| $t_k = 1.0$ mm | X | X | X | X | | X | | | | X | | X |
| $t_k = 1.6$ mm | X | X | X | X | X | X | X | | | X | X | |
| max. magn. pressure $p_{magn,max}$ [MPa] | | | | | 102 | 119 | 141 | | | | | |

Figure 3: Summary of investigated parameter combinations (see Figure 1a)

For the joining experiments, a ten-turn compression coil with an effective length of $l_c = 60$ mm and an inner diameter of 40 mm was used. The coil was connected to a Maxwell Magneform pulse generator with a capacity of $C = 363$ μ F, an inner resistance of $R_i = 5.4$ m Ω and an inner inductance of $L_i = 78$ nH. Prior to the joining experiments, free tube compression experiments were conducted to measure the compression speed as a function of displacement using the Photon Doppler Velocimetry (PDV) [15]. In this way, the joint strength can be correlated to the collision velocity between tube and mandrel.

The joint quality was determined by pull-out test using a Zwick Z250 tensile testing machine. The pull-out speed was set to a constant value of 0.1 mm/s. The connection strength was defined as force for which the first relative movement between the two joining partners occurs [8, 10], whereas a plastic elongation of 0.01 % was defined as threshold value for the allowed relative movement. Additionally, micrographs of the joined components were produced to investigate the deformation behavior of the knurling teeth. For that purpose, slices with a thickness of 10 mm out of the middle of the joining zone were grinded, polished and subsequently analyzed by optical microscopy.

Before performing the destructive pull-out tests, the joining regions of the specimens were imaged in 3D by X-ray micro computed tomography in order to analyze the

deformation of the hollow mandrel due to the magnetic pressures acting on the tube. For this non-destructive examination a high-performance computer tomography system equipped with two microfocus X-ray tubes (with directional target and with transmission target, respectively) was used: The X-rays are emitted from the focal spot on the target of the microfocus tube. Due to the interaction processes with matter, they are attenuated during penetration through the specimen. After penetration, the attenuated X-radiation is recorded by a large-sized flat-panel detector which contains 2048 x 2048 square pixels, each of which exhibiting an edge length of 200 μm . The samples were tomographically scanned with a maximum X-ray photon energy of $E = 180 \text{ keV}$. Exploiting the X-ray beam divergence, the joining region of the specimen was projected onto the detector plane with a maximum possible magnification of $m \approx 4.5$ given by the ratio of the focus-detector distance (900 mm) to the focus-object distance (200 mm). The joined specimen was fixed to the turntable of the 7-axis manipulator and rotated about the rotary axis of that table (which almost coincides with the longitudinal axis of the joined structure). With the X-ray sensitive flat-panel detector, cone-beam projections of the specimen's region-of-interest were acquired at 900 equally spaced angular positions of the turntable during circular CT-scanning. From these projections, tomograms (consisting roughly of $900 \times 900 \times 1600$ voxels) were reconstructed with software which is based on the Feldkamp algorithm [16]. The achieved voxel edge length was 45 μm . For visual inspection and quantitative analysis, from each reconstructed 3D tomogram, an xz-slice image revealing a virtual longitudinal cut through the joining region was extracted.

5 Results and Discussion

Prior to the discussion of the results obtained by pull-out tests, the interlocking mechanism caused by the knurled surface structure should be analyzed. Micrograph examinations of the joined components revealed that regardless of knurling pitch t_k , initial gap a_0 or charging energy E_c , no indentation of the knurling teeth into the outer joining partner occurred. Instead, a deformation of the knurling teeth could be observed, which increased with a rise of the collision velocity v_{Coll} . By way of example, the micrographs for specimens with a knurling pitch of $t_k = 1.6 \text{ mm}$, that were joined with a charging energy of $E_c = 6 \text{ kJ}$, are shown in Figure 4 to illustrate this deformation behavior.

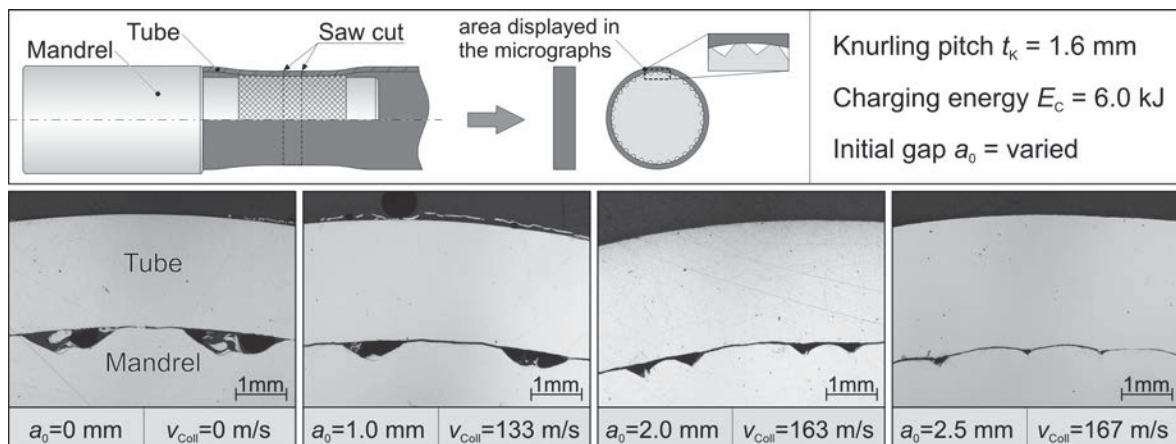


Figure 4: Micrographs of the cross-sectional area in the middle of the joining zone

With regard to the connection strength under static load, a deformation rather than an indentation of the knurling teeth is undesirable because of the missing undercut. Anyhow, the results of the pull-out tests in the following chapters proved that tube's strength can be reached. In case of dynamic loading, this deformation behavior is even beneficial as notches caused by an indentation might reduce the fatigue life of the connection.

5.1 Effect of Knurling Pitch and Collision Velocity

The effect of the knurling pitch t_k on the joint strength can be discerned from Figure 5, that shows the specific joint strength for the three investigated knurling pitches plotted against the initial gap a_0 for charging energies of $E_C = 4.8$ kJ (Figure 5a) and $E_C = 7.2$ kJ (Figure 5b), respectively. The axial joint strength F_{ax} determined by pull-out tests was divided by the tube's yield force $F_{p0,2}$ (56 kN) to obtain a dimensionless value. Additionally the strength of interference-fit joints is given as reference to evaluate the effectivity of the investigated interlocking mechanism. Moreover, the collision velocity between tube and mandrel is plotted against the initial gap a_0 and scaled on the secondary ordinate.

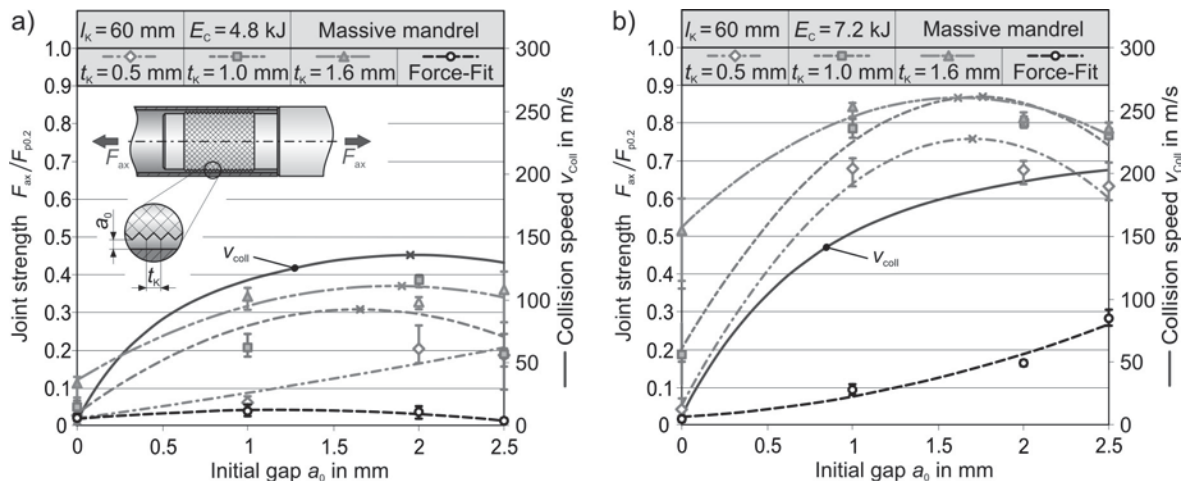


Figure 5: Effect of knurling pitch t_k on the joint strength in case of charging energies of (a) $E_C = 4.8$ kJ and (b) $E_C = 7.2$ kJ

In principle the results in Figure 5 reveal that a coarse knurling leads to higher joint strengths than a fine knurled surface structure. This also applies to the results in case of a charging energy of $E_C = 6.0$ kJ which are not described in this article. The decreasing difference in the joint strength between a knurling pitch of $t_k = 1.0$ mm and $t_k = 1.6$ mm, that can be observed in Figure 5b, is no exception to this, but can rather be attributed to the fact that the joint strength lies within the range of the tube's yield strength. Thus, the tube starts to yield before a failure of the joint occurs so that differences in the connection strength are not detectable any more.

According to [13] the highest impact velocity causes the highest connection strength if all other parameters remain equal. This assumption is approved by the strength and velocity plots in Figure 5a. Hence, in case of optimal joint design, the value of the initial gap between tube and mandrel should match with the value that causes the highest collision velocity. However, the plots in Figure 5b point out that this is not a sufficient

condition to guarantee the highest connection strength as the point of maximum joint strength and maximum collision velocity diverge from each other significantly.

For a more detailed analysis of the correlation between connection strength and collision velocity, Figure 6 can be used. It shows the specific connection strength plotted against the collision velocity in case of a knurling pitch of $t_k = 1.0$ mm. In comparison to Figure 5, the effect of charging energy E_c and initial gap a_0 on the collision velocity can be analyzed separately. The diagram reveals that a rising collision velocity caused by an increase of the charging energy leads to an increasing connection strength in any case. If the increase of the collision velocity is caused by an increasing gap size, the joint strength is affected by two additional effects. On the one hand the gap size is increased by decreasing the outer diameter of the mandrel, which lessens the area of contact between the two joining partners and has a negative impact on the connection strength. On the other hand, roundness measurements on joined specimens proved that an increased gap size results in an increasing roundness deviation, that may lower the connection strength as well.

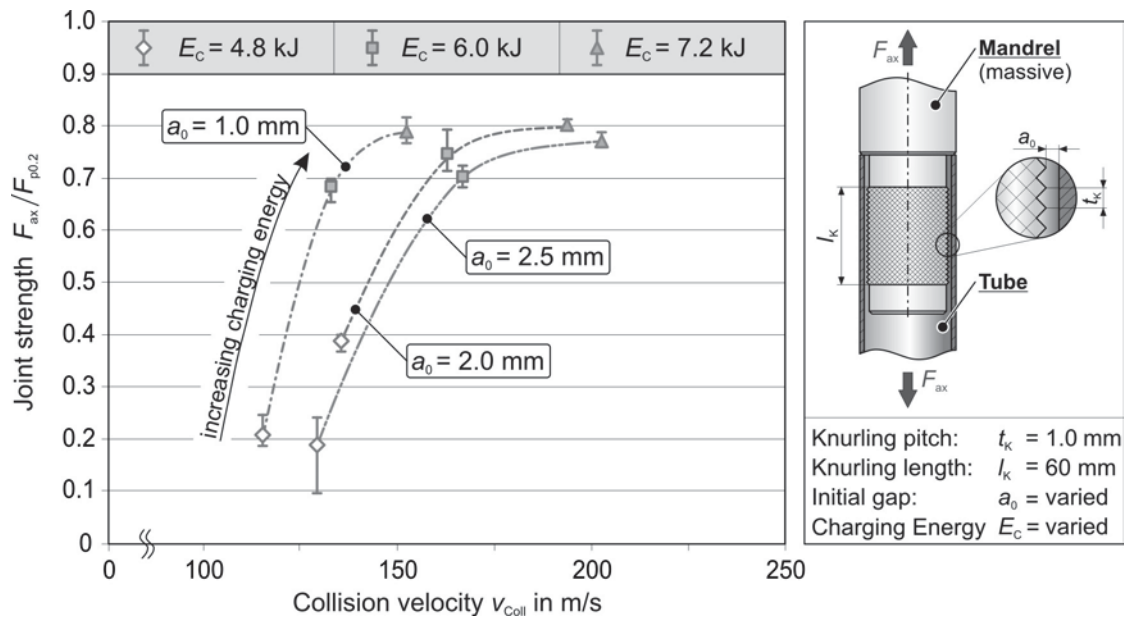


Figure 6: Effect of the collision velocity on the joint strength ($t_k = 1$ mm, $l_k = 60$ mm)

Consequently, an increase of the gap size only results in a rise of the connection strength if the positive effect of increasing collision velocity predominates the negative effects of decreasing contact area and increasing roundness deviation.

With regard to the results in Figure 6, this condition is met for a change of the gap size from $a_0 = 1$ mm to $a_0 = 2$ mm as an increase of the connection strength can be observed for all charging energies. Augmenting the gap size from $a_0 = 2.0$ mm to $a_0 = 2.5$ mm only leads to a slight increase of the collision velocity that cannot compensate the negative effects mentioned above and thus causes a decrease of the joint strength. Based on this result it can be concluded that in case of small collision velocity gradients, rather smaller gap sizes should be preferred as the advantage of the slight increase of velocity is completely eroded by the negative effects of decreasing contact area and increasing roundness deviation.

5.2 Effect of Knurling Length

Experimental investigations to analyze the effect of varying knurling lengths were conducted using specimens with a knurling pitch of $t_k = 1.0$ mm and a constant charging energy of $E_c = 7.2$ kJ. The knurling length was varied with a step size of 20 mm within the range of $l_k = 20$ mm to $l_k = 60$ mm. The results in Figure 7 show that a decrease of the knurling length from $l_k = 60$ mm to $l_k = 40$ mm has no influence on the connection strength at all, whereas for a reduction from $l_k = 40$ mm to $l_k = 20$ mm a decrease of 20% on average can be observed. This non-linear correlation between connection strength and knurling length is in accordance with the results obtained by Eguia et al. [13] and can be attributed to the non-uniform distribution of the magnetic pressure along the tube axis [17]. As the magnetic pressure progressively decreases towards the coil edges, the collision velocity between tube and mandrel will show a similar dependency on the axial position. Considering the results regarding the effect of the collision velocity on the joint strength, this varying velocity along the tube axis is the reason for the non-linear correlation between knurling length and joint strength.

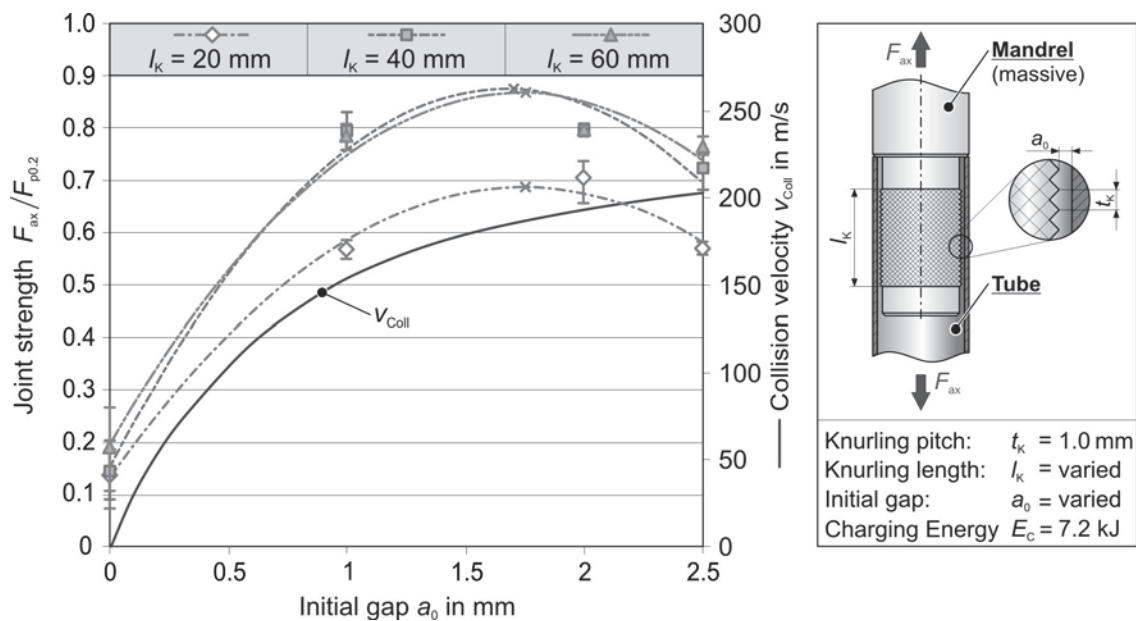


Figure 7: Effect of knurling length l_k on the joint strength ($t_k = 1$ mm, $E_c = 7.2$ kJ)

Based on these results it can be concluded that a decreasing ratio of knurling length l_k to coil length l_c leads to an increasing ratio of joint strength to knurling length.

5.3 Effect of Mandrel Stiffness

The use of hollow mandrels seems to be a promising approach to achieve a considerable weight reduction of the joint zone. For this reason, the effect of different mandrel stiffnesses on the joint strength was investigated. Mandrels with a knurling pitch of $t_k = 1.0$ mm and a knurling length of $l_k = 60$ mm were joined with a constant charging energy of $E_c = 6.0$ kJ for this series of experiments. The stiffness was adapted by varying the mandrel's inner diameter. Specimens with values of $Q_A = 1.07$, 1.27 and 1.46 were

investigated. The value Q_A defines the relation between the cross-sectional area of mandrel and tube (see explanation in Figure 8) so that an increase of Q_A leads to a decrease of the mandrel's inner diameter in case of a constant gap a_0 . The results shown in Figure 8 reveal that a decreasing inner diameter of the mandrel, respectively an increase of its stiffness, leads to a rise of the joint strength. In comparison to the strength of connections that were produced using massive mandrels, a drop of 50% on average can be observed. As the interference fit is negligible due to identical materials for tube and mandrel [8], the joint strength of the connections must be attributed to an interlock effect caused by the knurling structure. It can be suggested that the negative correlation between the mandrel's inner diameter and the joint strength results from a deformation of the inner joining partner itself which hinders the deformation of the knurling teeth.

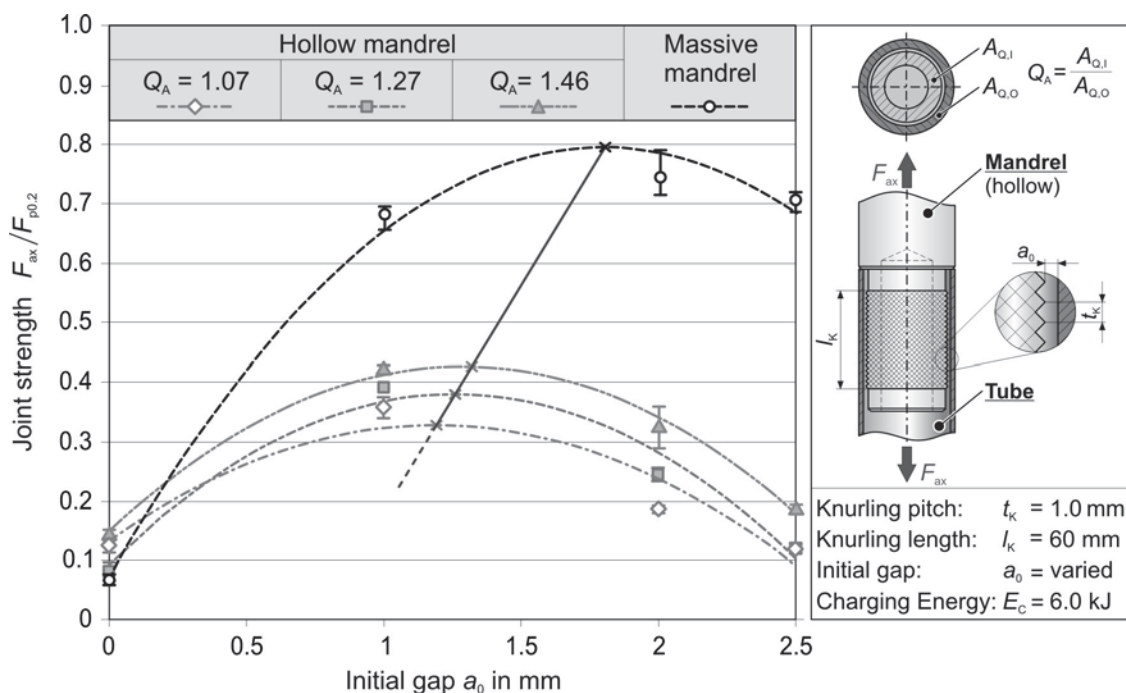


Figure 8: Effect of mandrel stiffness on the joint strength ($t_k = 1 \text{ mm}$, $E_C = 6.0 \text{ kJ}$)

This assumption was proved by computed tomography that was used to analyze the deformation behavior of the inner joining partner in a qualitative and quantitative manner. Measurement of the mandrel's inner diameter in the 3D tomograms revealed an increasing contraction of the tube in case of a decreasing ratio Q_A . By way of example Figure 9 shows the sectional view along the tube's axis for the three investigated tube stiffnesses and an initial gap of $a_0 = 0 \text{ mm}$.

Summing up the results regarding the effect of the mandrel stiffness, it can be concluded that massive mandrels should be used if maximization of the joint strength is the main interest. If the efforts in joint design mainly focus on weight reduction, hollow mandrels with adapted stiffness should be preferred. A combination of maximum joint strength and weight reduction may be achieved by inserting a massive steel mandrel into the inner joining partner during the joining process that can be removed afterwards [18]. In this way, the deformation of the hollow mandrel is inhibited and the interlock could be improved. However, further investigations are required to prove this approach.

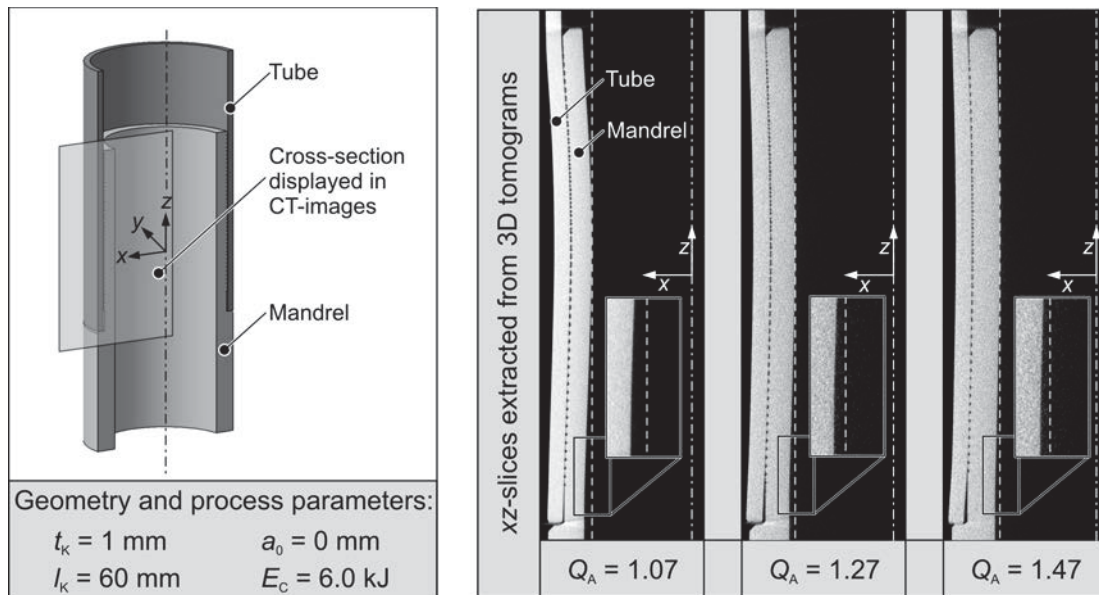


Figure 9: Sectional views along the tube's axis of computed tomographic images ($t_k = 1 \text{ mm}$, $E_c = 6.0 \text{ kJ}$, $a_0 = 0 \text{ mm}$)

6 Conclusion

Joining by electromagnetic tube compression using mandrels with knurled surface structure was investigated by experimental means, whereas both joining partners were made of the same aluminum alloy AA6060-T6. Micrographs of the joined specimens revealed, that only a slight indentation of the knurling teeth into the outer joining partner occurs. Instead, a deformation of the knurling teeth could be observed. Anyhow, pull-out tests proved, that in spite of the missing indentation, an interlock between the two joining partners is generated, that leads to a significant increase of the connection strength in comparison to interference-fit connections. Considering the results, a coarse knurl pattern should be preferred within the joint design and the knurling zone length l_k should be designed significantly shorter than the coil length l_c as the regions close to the coil edges only contribute to the connection strength in a marginal manner. The use of hollow mandrels for reason of weight reduction is only recommendable if the connection strength is just a boundary condition and not the parameter to be maximized. Increasing the collision velocity by increasing the gap size between tube and mandrel should only be considered as an alternative to an increased charging energy, if the additional acceleration of the tube leads to significant increase of the collision velocity. Otherwise countervailing effects might reduce the joint strength even if a slight increase of velocity might be observed.

Further research should concentrate on the development of analytical approaches that describe the deformation behaviour of the knurling teeth depending on charging energy or collision velocity to facilitate the process design and reduce the need for experimental investigations. Moreover it should be investigated whether the use of different aluminum alloys for mandrel and tube is a suitable approach to combine the interlock caused by the knurling structure with a pronounced interference fit between the two joining partners.

References

- [1] *Wegerdt, C.; Thoms, V.; Franke, R.; Carstensen, H.*: Mechanische Fügetechnik. Tagungsband der 72. Tagung des Wissenschaftlichen Rates der AIF, Düsseldorf, 1999, p. 6.1-6.20.
- [2] *Nationale Plattform Elektromobilität*: Zweiter Bericht der Nationalen Plattform Elektromobilität, Berlin, 2011.
- [3] *Schönherr, M.*: Formgebung durch den Strang. Maschinenmarkt, 2003, Issue 11, p. 24-26.
- [4] *Fouhy, K.*: Alu-Strangpressprofile optimal herstellen. Maschinenmarkt, 2003, Issue 11, p. 3.
- [5] *v. Finckenstein, E.*: Ein Beitrag zur Hochgeschwindigkeitsumformung rohrförmiger Werkstücke durch magnetische Kräfte. In: Fortschritt Berichte VDI-Z, Reihe 2, Nr. 17, VDI-Verlag, Düsseldorf, 1967.
- [6] *Winkler, R.*: Hochgeschwindigkeitsbearbeitung. VEB Verlag Technik, Berlin, 1973.
- [7] *Lange, K.*: Umformtechnik – Band 4: Sonderverfahren, Prozesssimulation, Werkzeugtechnik, Produktion. 2. Auflage, Springer Verlag, Berlin, 1993.
- [8] *Weddeling, C.; Woodward, S. T.; Marré, M.; Nellesen, J.; Psyk, V.; Tekkaya, A. E.; Tillmann, W.*: Influence of groove characteristics on strength of form-fit joints. Journal of Materials Processing Technology, 211 (2011), Issue 5, p. 925-935.
- [9] *Bühler, H.; Bauer, D.*: Ein Beitrag zur Magnetumformung rohrförmiger Werkstücke. Werkstatt und Betrieb, 110 (1968), Issue 9, p. 513 – 516.
- [10] *Bühler, H.; v. Finckenstein, E.*: Fügen durch Magnetumformung – Lösekräfte von Sickenverbindungen aus Stahl. Werkstatt und Betrieb, 101 (1968), Issue 11, p. 671-675.
- [11] *Golovashchenko, S.*: Methodology of Design of Pulsed Electromagnetic Joining of Tubes. Proceedings of the TMS Symposium “Innovations in Processing and Manufacturing”, New Orleans, LA, USA, 2001, p. 283-299.
- [12] *Park, Y.-B.; Kim, H.-Y.; Oh, S.-I.*: Design of axial/torque joint made by electromagnetic forming. Thin Walled Structures, 43 (2005), p. 826-844.
- [13] *Eguia, I.; Zhang, P.; Daehn, G. S.*: Improved Crimp-Joining of Aluminum Tubes onto Mandrels with Undulating Surfaces. Proceedings of the 1st International Conference on High Speed Forming 2004 (ICHSF), Dortmund, 2004, p. 161-170.
- [14] *Marré, M.; Brosius, A.; Tekkaya, A. E.*: Joining by Compression and Expansion of (None-) Reinforced Profiles. Advanced Materials Research, 43 (2008), p. 57 – 68.
- [15] *Vivek, A.; Kim, K.-H.; Daehn, G. S.*: Simulation and instrumentation of electromagnetic compression of steel tubes. Journal of Materials Processing Technology, 211 (2011), p.840-850.
- [16] *Feldkamp, L. A.; Davis, L. C.; Kress, J. W.*: Practical cone-beam algorithm. Journal of the Optical Society of America, 1 (1984), Issue 6, p. 612 – 619.
- [17] *Beerwald, C.*: Fundamentals for Process Dimensioning and Design of Electromagnetic Forming (in German). Dr.-Ing. Thesis, Universität Dortmund, 2004.
- [18] *Weddeling, C.; Woodward, S.; Nellesen, J.; Psyk, V.; Marré, M.; Brosius, A.; Tekkaya, A. E.; Daehn, G. S.; Tillmann, W.*: Development of design principles for form-fit joints in lightweight frame structures. Proceedings of the 4th International Conference on High Speed Forming 2010 (ICHSF), Dortmund, 2010, p. 137 – 148.