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STUDY OF SHAFT-HUB ASSEMBLY TECHNOLOGY USING ADHESIVE

Sándor RAVAI-NAGY, Nicolae MEDAN, Iacob Eden ORMENIȘAN

Abstract: *Shaft - key - hub assembly is often used in industry. In order to reduce costs, the replacement of key and using an adhesive layer is tried. The purpose of the work is to compare the shaft-key-hub assembly with the shaft-hub bonded assembly from the point of view of the maximum transmissible torque. The shear strength of the adhesive layer was determined and compared to the shear strength of the key under the same operating conditions. The shear strength of the adhesive layer was determined experimentally. Based on the experimental data obtained from the static tests, it is found that there are no differences in terms of transmitted torque. In terms of costs, there is a decrease in manufacturing costs.*
Key words: *adhesive, hub-shaft assembling technology, adhesive layer shear strength.*

1. INTRODUCTION

The shaft-hub assembly is approached from the perspective of reducing production costs and material consumption. The possibility of adhesive bonding the hub to the shaft is studied to reduce the consumption of materials as well as the possibility of automating the assembly process.

Reducing the number of assembly components facilitates the assembly operation. For a robotization of the shaft-hub assembly, a complex technology is needed through which we must solve the mutual positioning between the hub shaft and shaft key to assemble them. A robotic cell made for this purpose would be expensive. To simplify the assembly technology, a variant would be to bond the hub to the shaft using adhesive layer.

Through the technology of bonding the hub to the shaft, advantages are obtained in terms of manufacturing costs, material consumption and assembly. When bonding, the adhesive layer will replace the shaft, the axial locking elements of the wheel, the shaft channels in the shaft and hub.

Classical assemblies, using shaft – hub – shaft key, from the point of view of dimensioning, calculation of shaft key and moments, assembly conditions have been extensively studied in the specialized literature [3, 4, 8].

Several works have studied adhesive bonding assemblies. Mechanical properties of hub/shaft joints adhesively bonded was presented in paper [7]. In paper [1] the influence of the assembly process on the shear strength of shaft–hub hybrid joints were studied. Calculation of the strength of cylindrical assemblies [6] has been approached. The increase of anaerobic polymer materials resistance to vibration loads [5] are presented. Studies have been carried out regarding stell-composite hybrid assemblies [2].

In figure 1, we present comparatively the structure of the shaft “1” – hub ”2” adhesive bonding assembly, respectively shaft “3” – hub “4” shaft key “5” by the classical method.

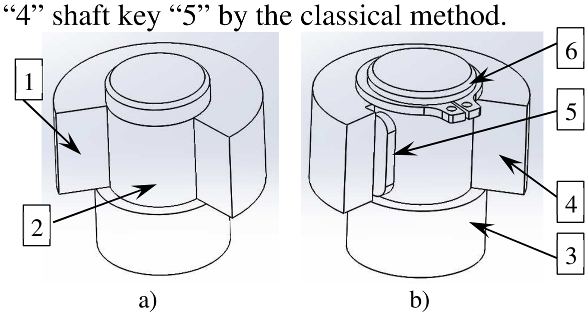


Fig. 1. a) Bonded assembly shaft – hub, b) Classical assembly shaft – key – hub

Comparing the structure of the assemblies represented in figure 1, we find certain differences:

a) From an organological point of view, by using the adhesive we do not need:
- shaft key "5";
- shaft with shaft key channel "3";
- hub with shaft key channel "4";
- axial hub locking system "6" (in this case a circlip).

b) From the assembly point of view, it changes substantially:
- There is no need to orient the shaft key and the related channel in the shaft for assembly;
- No additional energy is needed to press the shaft key into the shaft;
- There is no need to orient the shaft key-shaft assembly with respect to the shaft key channel in the wheel;
- No need to assemble the axial hub locking system.
- It is necessary to apply the adhesive layer on the hub-shaft contact surface.

b) From a manufacturing point of view:
- The shaft key channel in the shaft is not processed;
- The shaft key channel in the hub is not processed;
- The shaft for the axial wheel locking system is not machined.

Consequently, the adhesive layer will have the role of both transmitting the torsional moment and the axial fixation of the hub on the shaft. The hub-shaft assembly becomes more compact.

Considering the above, in the case of robotic assembly, a cell will be required that:
- manipulate the shaft and the hub;
- to apply the adhesive layer;
- insert the shaft into the hub;
- to manipulate the completed assembly.

To compare the torque transmitted by an assembly bound with adhesive and a classical assembly using shaft key, we performed the experiment presented below.

2. EXPERIMENT INPUT PARAMETERS

The experiment carried out required the design and execution of some samples to materialize a shaft section and the bore of a wheel.

Initial data of the proposed experiment:
- Assembly diameter: Ø20 mm;
- Wheel material: S235J0 (EN 10025);
- Shaft material: 1.0503 (EN 10277);
- Roughness of the contact surfaces:
    - shaft: Ra=1,6μm;
    - wheel: Ra=1,6μm;
- Bore diameter: Ø20H8(+0 /-0.033) mm – constant.
- Shaft diameter:
    - batch 1: Ø20 (-0.025 / -0.075) mm;
    - batch 2: Ø20 (-0.150 / -0.200) mm;
    - Wheel width: 16 mm.
- Adhesive layer thickness (results from the shaft-hub mating):
    - 0,050 mm; / 0,100 mm.
- Adhesive drying time:
    - 24 hours (1 day); / 168 hours.

3. THE SHAPE AND CONTROL OF THE SAMPLES

The bores were machined from a sheet rectified on both sides to ensure the flatness of the surfaces. The holes were machined by drills, followed by reaming. The manufacturing technology ensured the perpendicularity of the holes on the plate, the dimensional accuracy of the holes and the quality of the surface of the bores.

After processing each bore was numbered.

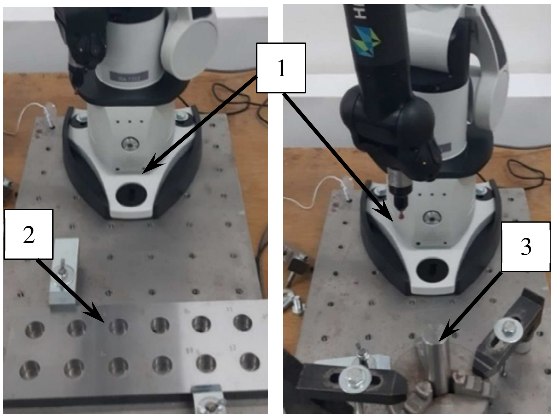
The shafts were machined by turning on a CNC lathe, followed by marking them.

The bores were machined to the same diameter Ø20H8(+0/-0.033). In order to obtain 2 different thicknesses of the adhesive layer, the shafts were processed in two batches of 4 pieces each.

Batch 1 (4 shafts) were proposed for execution at the diameter of Ø20 mm (-0.025/-0.075) so that the thickness of the adhesive layer is around 0.05 mm.

Batch 2 (4 shafts) were proposed for execution at the diameter of Ø20 mm (-0.150/-0.200) so that the thickness of the adhesive layer is around 0.1 mm.

A Hexagon RA-7312 measuring arm "1" was used to measure hubs in sample "2" and shafts "3" diameters respectively (figure 2).



a) hub b) shaft

Fig. 2. Samples and their control

Measured dimensions for hubs and shafts are centralized in Table 1. The values of the thickness of the adhesive layer, following the calculations, are presented centrally in table 2.

Table 1.

Measured diameters and cylindricity for hubs and shafts

Hub	**Ø** [mm]	**/O/** [mm]	**Shaft**	**Ø [mm]**	**/O/ [mm]**
A1	20.025	0.003	a1	19.972	0.004
A2	20.029	0.005	a2	19.966	0.011
A3	20.031	0.027	a3	19.932	0.007
A4	20.029	0.035	a4	19.969	0.008
A5	20.031	0.008	b1	19.824	0.013
A6	20.026	0.004	b2	19.803	0.018
A7	20.028	0.005	b3	19.821	0.012
A8	20.033	0.011	b4	19.814	0.008

The surface quality of the hubs and the shafts was measured using a TR-200 roughness meter and the values are presented in table 2.

Table 2.

The measured roughness of the contacting surfaces

Hub	**Ra**	**Shaft**	**Ra**
A1	1.044	a1	1.665
A2	0.933	a2	1.79
A3	1.08	a3	1.541
A4	0.903	a4	1.647
A5	0.867	b1	1.561
A6	1.029	b2	1.695
A7	0.928	b3	1.585
A8	0.979	b4	1.662
Average value			
	0.970		1.643

The thickness of the adhesive layer was determined by calculation according to relations (1) and (2).

Maximum thickness:

$$G_{i\,max} = \frac{A_{i\,max} - a_{i\,min}}{2} \tag{1}$$

Minimum thickness:

$$G_{i\,min} = \frac{A_{i\,min} - a_{i\,max}}{2} \tag{2}$$

where:

- $G_{i\,max}$ – maximum adhesive layer thickness [mm];
- $G_{i\,min}$ – minimum adhesive layer thickness [mm];
- $A_{i\,max}$ – maximum hub diameter [mm];
- $A_{i\,min}$ – minimum hub diameter [mm];
- $a_{i\,max}$– maximum shaft diameter [mm];
- $a_{i\,min}$ – minimum shaft diameter [mm];
- i – the order number of the assembly (i=1...8)

The determined values of the thickness of the adhesive layer are presented in table 3.

Table 3.

Adhesive layer thickness

Hub	**Ø hub**		**Shaft**	**Ø shaft**		**adhesive layer thickness**			**Average / batch**
	min.	**max.**		**min.**	**max.**	**min.** $G_{i\,min}$	**max.** $G_{i\,max}$	**average**	
	[mm]	[mm]		[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
A1	20.024	20.027	a1	19.97	19.974	0.025	0.0285	0.027	0.03475
A2	20.027	20.032	a2	19.961	19.972	0.0275	0.0355	0.032	
A3	20.018	20.045	a3	19.929	19.936	0.041	0.058	0.05	
A4	20.012	20.047	a4	19.965	19.973	0.0195	0.041	0.03	
A5	20.027	20.035	b1	19.818	19.831	0.098	0.1085	0.103	0.107
A6	20.024	20.028	b2	19.794	19.812	0.106	0.117	0.111	
A7	20.026	20.031	b3	19.815	19.827	0.0995	0.108	0.104	
A8	20.028	20.039	b4	19.81	19.818	0.105	0.1145	0.11	

Adhesive with the commercial name Loctite 638 was used in the experiment.

The characteristics of the adhesive according to the manufacturer are presented in table 4.

Table 4.

Features of Loctite adhesive 638

Physical Form	Liquid
Cure Type	Anaerobic Cure
Gap Fill	0.15 - 0.25 mm
Shear Strength, Steel	31.0 N/mm²
Chemical Type	Urethane methacrylate
Viscosity	2500.0 mPa·s (cP)

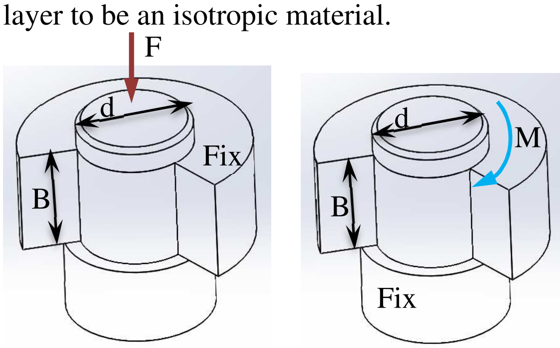
4. DETERMINATION OF THE SHEAR STRENGTH OF THE ADHESIVE

To determine the shear strength of the adhesive layer, an axial force F (fig. 3.a) will be applied to the bolt using the material testing machine. Simple and safe equipment and method.

In the experiment are used a TC100 material testing machine from LBG Srl Italy (load capacity: 100kN, resolution: 0.01kN).

Later, based on the experimentally obtained shear strength, we can also calculate the shear moment for the given assembly.

In the experiment we consider the adhesive layer to be an isotropic material.



a) b)

Fig. 3. The principle of experimental determination of the shear strength of the adhesive layer.

The shear strength from the torsional moment condition is (3) [8]:

$$\tau_f = \frac{2 \cdot M}{d \cdot \pi \cdot d \cdot B} \quad (3)$$

The shear strength from the axial force condition is (4) [8]:

$$\tau_f = \frac{F}{\pi \cdot d \cdot B} \quad (4)$$

were:

- M – torsion moment [Nm];
- F – axial force [N];
- d – shaft diameter [mm];
- B – wheel width (shaft–hub contact surface) [mm];
- τ_f – shear resistance [N/mm^2].

In the two cases, the surface after which the shear is produced is the same: $\pi \cdot d \cdot B$.

The experimental data obtained and the shear strength values calculated with relation 4 are presented in table 5.

Table 5.

Experimental data: Axial force – Shear resistance

Hub	Ø [mm]	Adhesive thickness [mm]	Axial force 1 day [kN]	Axial force 1 week. [kN]	Shear resistance 1 day [N/mm²]	Shear resistance 1 week. [N/mm²]
A1	20.025	0.027	25.965	29.07	25.796	28.88
A2	20.029	0.032	24.829	29.871	24.662	29.67
A3	20.031	0.05	25.225	31.338	25.053	31.124
A4	20.029	0.03	28.121	30.656	27.932	30.45
A5	20.031	0.103	28.142	31.375	27.95	31.161
A6	20.026	0.111	25.263	26.097	25.097	25.925
A7	20.028	0.104	22.244	24.774	22.096	24.609
A8	20.033	0.11	23.089	27.472	22.929	27.282

Table 6 shows the average values of the shear strengths according to the average thicknesses of the adhesive layer.

Table 6.

The average values of the shear strengths

Hub	Average	Shear resistance 1 day [N/mm²]	Shear resistance 1 day Average [N/mm²]	Shear resistance 1 week [N/mm²]	Shear resistance 1 week Average [N/mm²]
A1	0.04	25.796	25.861	28.88	30.031
A2		24.662		29.67	
A3		25.053		31.124	
A4		27.932		30.45	
A5	0.11	27.95	24.518	31.161	27.244
A6		25.097		25.925	
A7		22.096		24.609	
A8		22.929		27.282	

5. CASE STUDY OF THE MAXIMUM MOMENT TRANSMITTED BY A SHAFT – KEY – HUB ASSEMBLY AND A BONDED ASSEMBLY

After analysing the data, we find the influence of the thickness of the adhesive layer on its shear strength. The thickness of the adhesive layer negatively influences the shear strength of the adhesive layer.

From the point of view of the adhesive hardening, we find that after 1 day the assembly can already be requested. Depending on the 1-day or 7-day curing time, we see a difference of 10-14%. And in this case we notice the advantage of the reduced thickness of the adhesive.

For the case study, regarding the maximum moment transmitted by the shaft key or adhesive, a shaft-hub transmission with a diameter of 20 mm and wheel width of 16 mm was chosen. The equivalent shaft key: (Parallel key A6 x 6 x 16 DIN 6885), made by C45.

5.1. Calculation of the shear moment of the shaft key.

To determine the feather shear moment, the classic moment formula (5) was used.

$$M = F \cdot l = F \cdot d/2 \tag{5}$$

were:

M – shear moment [Nm];

F- cutting force [N];

l – arm of force [mm];

d – diameter of the shaft [mm].

To determine the shear force, we consider the shaft key stress as in the process of cutting sheet metal with scissors with parallel blades. In this case we have:

$$F = S \cdot \tau_{sB\,max} \tag{6}$$

$$\tau_{sB\,max} = 0{,}8 \cdot R_{m\,max} \tag{7}$$

were:

F- cutting force [N];

S- shear area [mm^2];

$\tau_{sB\,max}$- maximum shear strength [N/mm^2];

$R_{m\,max}$ – maximum tensile strength [N/mm^2].

In presented case:

$R_{m\,\max}$ =620 N/mm2, for C45 material

$S = w \cdot lc$

were:

w- shaft key width [mm]

lc – calculation length of the shaft key

S_k – shaft key section [mm^2].

$$S_k = \pi \cdot w + w \cdot lc = 78{,}84\ mm^2$$

Shaft key shear force:

$$F = S \cdot \tau_{sB\,max} = 39105\ \text{N}$$

The shear moment of the feather according to relation (5) is:

$$M = F \cdot l = 39105\ N \cdot 10\ mm = 391\ Nm$$

5.2. Calculation of the shear moment in the case of bonded shaft-hub assembly

The shear moment of the adhesive layer is calculated from the area of the contact surface between the shaft and the hub and the shear strength of the adhesive layer already determined experimentally.

$$M = F \cdot l = \pi \cdot d \cdot \tau_{sB\,adeziv} \cdot B \cdot l = 301{,}4\ Nm$$

There is a decrease in the transmitted moment in the case of the bonded assembly compared to the parallel shaft key assembly with rounded ends considered in the shear area.

6. CONCLUSION

Following the presented study, we tried to cover some gaps in the specialized literature regarding the applicability of wheel-shaft bonding. We determined the shear strength of the adhesive layer for a bonded wheel-shaft assembly and the transmitted moment. After the experiment it was found that the transmitted moment when using adhesive is comparable to the transmitted moment in the case of a parallel key assembly. Following the case study, is found that the bonded assembly transmits a 23% lower torque compared to the shaft-key-hub assembly.

The thickness of the adhesive layer negatively influences shear strength. It is found that increasing the thickness of the adhesive layer from 0.035 mm to 0.107 mm leads to a decrease in shear strength by 10%.

The construction of the assembly is simpler in the case of adhesive bonded the hub to the shaft. The use of a bonded assembly implicitly leads to a decrease in the number of components resulting in a decrease in manufacturing costs.

As a result of the experiments, new research directions are opened:

- The influence of the: roughness of the surfaces in contact, couples of different type of materials, dimensions of shaft and hub;
- Development of studies for industrial steel -plastic assembly. Identification of adhesives according to the chemical composition of plastic materials;
- Realization of a device that allows the direct measurement of the transmitted torque.

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STUDIUL TEHNOLOGIEI DE ASAMBLARE ARBORE – BUTUC PRIN LIPIRE

Scopul inițial al lucrării a fost realizării unui studiu pentru robotizarea asamblării ansamblului arbore – pană – butuc. Pe parcurs a apărut idea eliminării penei din ansamblu și înlocuirea ei cu o peliculă de adeziv. În lucrare sunt prezentate rezultatele studiului experimental pentru lipirea metalelor la temperatură ambiantă. Studiul a fost orientat pentru a obține informații, date experimentale referitoare la posibilitatea înlocuirii ansamblului arbore- pană – butuc cu ansamblul arbore – butuc lipit. Pe baza datelor experimentale obținute în urma încercărilor statice se constată că din punct de vedere a momentului transmis nu sunt diferențe. Din punct de vedere a costurilor rezultă o scădere a costurilor de fabricație. Nu mai este nevoie de pană iar canalele de pană în arbore respectiv in butuc nu se mai execută. Aplicarea adezivului la fel se poate automatiza.

Sándor RAVAI NAGY, Lecteur, PhD. North University Centre at Baia Mare, Faculty of Engineering, Technical University of Cluj-Napoca, V. Babes Str. 62A, 430083 Baia Mare, Romania**,** tel.: 0264-202975, sandor.ravai@imtech.utcluj.ro

Nicolae MEDAN Lecteur, PhD. North University Centre at Baia Mare, Faculty of Engineering, Technical University of Cluj-Napoca, V. Babes Str. 62A, 430083 Baia Mare, Romania**,** tel.: 0264-202975, nicolae.medan@imtech.utcluj.ro

Iacob Eden ORMENISAN, MsC. North University Centre at Baia Mare, Faculty of Engineering, Technical University of Cluj-Napoca, V. Babes Str. 62A, 430083 Baia Mare, Romania**,** tel.: 0264-202975, edi.iacob.ormenisan@gmail.com