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SHEAR STRENGTH TESTING OF HARDFACED SAMPLES USING SPECIAL TOOL ON AN UNIVERSAL TESTING MACHINE

ODREĐIVANJE SMICAJNE ČVRSTOĆE NAVARENIH UZORAKA UPOTREBOM SPECIJALNOG ALATA NA UNIVERZALNOJ MAŠINI ZA ISPITIVANJE

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Abstract

Complex working conditions of forging dies are the most frequent causes of their damage, requiring suitable hard facing repair procedures. The method of determining the bond strength between the hardfaced layer and the base material is explained in details, and the relation between hardfaced layer output results and the applied technology is established. Shear testing of materials has proven to be one of the most difficult areas of mechanical property testing. Shear modulus measurements are mainly accurate, but it is very difficult to measure shear strength. Edges, material coupling, non-pure shear loading, non-linear behaviour, imperfect stress distribution and coupling with normal stresses make shear strength determination difficult. None of the available test methods are without inaccuracies. Therefore, in structural applications, shear strength data should be used very carefully, on a case-by-case basis, appreciating the consequences of potential inaccuracies of the used values.

Izvod

Ovaj rad ukazuje na složene uslove rada kovačkih alata, koji su najčešće uzrok njihovog oštećenja i prikazuje izbor najpovoljnije tehnologije reparaturnog navarivanja. Detaljno je objašnjen metod za određivanje jačine veze između navarenog sloja i osnovnog materijala i data je veza između izlaznih karakteristika navarenog sloja i primenjene tehnologije navarivanja. Ispitivanje materijala smicanjem je pokazalo da ono spada u grupu najtežih ispitivanja materijala. Merenja modula smicanja su relativno tačna ali je veoma teško meriti smicajnu čvrstoću. Ivice, nagomilavanje materijala, nejednako smicajno opterećenje, nelinearno ponašanje materijala, nejednaka raspodela napona i udvajanje sa normalnim naponima čini određivanje smicajne čvrstoće teškim. Nijedan od dostupnih metoda ispitivanja nije potpuno tačan. Dakle, prilikom primene na konstrukcijama, rezultate smicajne čvrstoće treba koristiti pažljivo, od slučaja do slučaja, uzimajući u obzir posledice od potencijalnih netačnosti rezultata.

INTRODUCTION

Improved performance and prolonged lifetime are basic demands for industrial plants and machineries. The weld deposition of hard facing alloys is commonly employed in industry to increase the lifetime of components subjected to different kinds of wear /1, 2/. In hot forging, both moulds and dies are subjected to severe mechanical and thermal loads. The lifetime of dies used for production of forged parts is variable and determined by wear rate, plastic deformation and thermal and mechanical fatigue. Those tools are subjected to extreme temperature and high pressure in multiple cycles while maintaining dimensional stability, /3/. Occurrence of damage on a pair of hot-forging dies, made of hot-working die steel, has been analysed in /4/. Gas nitrided dies under different conditions were sectioned and examined using optical microscopy and Vickers micro-hardness measurements to reveal three mechanisms of wear: thermal fatigue, mechanical fatigue and abrasion. A couple of important issues of hot forging die failures are summarized in /5/. Influencing factors as die materials, die design, die manufacturing and forging operations are described.

Here shear strength values at interfaces have been considered and compared among different weld deposits made by different procedures. Furthermore, microstructures and hardness survey in the transverse section of the weld deposits are made, so to understand the interface shear strength. Since some parts of the forging dies are extremely exposed to shear during hot forging, it is vital to establish a relation between the shear resistance (of the base metal and the hardfaced layer, or the boundary surface between the base metal and the hardfaced layer), the hard facing technology and heat treatment, /12, 13, 14/.

With this aim, a special tool is constructed and mounted on an universal mechanical testing machine to enable estimates of absolute and relative bearing capacities of characteristic cross-sections. Obtained experimental results are used primarily to assess the chosen repair technology, but they can also be useful in dimensioning new forging dies, because the ratio of the shear to tensile strength could then be taken into account as the calculating value. This paper also deals with the most frequent causes of damage, types of steels used for forging dies, the choice of hard facing technology and filler materials, and it offers a plan how to conduct experiments during model testing. All tests are performed on models made of the same material as the forging dies. In this way, the output results may be correlated to the chosen procedure and hard facing technology.

Model investigations have been performed of filler materials for the regeneration of damaged parts of construction mechanization in /15/, and in /16/ authors have investigated a selection of the most appropriate hard facing repair technology of working parts on universal construction machinery, gears /17/, and belt wagons /18/.

FORGING TOOL MATERIALS

Hot work tool steels (forging and pressing tools, die casting tools, rollers for hot rolling etc.) must have good mechanical properties, such as strength and toughness, and the ability to retain them at elevated temperatures. Furthermore, they must have high resistance to wear, sufficient hardenability, good thermal conductivity, stability during processes of oxidation and decarburization, low coefficient of linear expansion, and resistance to surface cracking at alternate heating and cooling, /11/. If temper brittleness should appear, /13/, it can sometimes be eliminated by appropriate technological measures that involve rapid cooling in the temperature range 500-550ºC. Forging dies and press tools operate at elevated temperatures (up to 600ºC) and they are subject to impact loading and static pressure. Steel alloys with Cr, V, Mo and with 0.3-0.6% C have good hardenability needed for larger tools as well as high hardness at elevated temperatures, /11/.

Hard facing of two typical steels for forging dies are studied: Č5742 (JUS) – 56NiCrMoV7 (DIN) – 55CrMo 8 (EN) – used for all kinds of forging tools, and Č4751 (JUS) – X38CrMoV51 (DIN) – X27CrMoV 51 (EN) – primarily for casting dies of non-ferrous metals, particularly aluminium alloys and brass. These steels are mainly used in forging workshops. Their properties are given in Tables 1 and 2.

Since forging dies used in blacksmithing are in quenched and highly tempered condition, all the samples (models) here used are also quenched and tempered in order to simulate real operating conditions. After the heat treatment, hardness is measured on samples, and it varied from 40-42 HRC for 55CrMo8 and from 41-49 HRC for X27Cr MoV 51. Because of the carbon content (C > 0.35%) and the thickness of hardfaced layers, preheating up to about 300°C was necessary.

A selection of the most suitable hard facing technology and filler materials, and the preparation of specimens for experimental investigations, hardness distribution and microstructure of characteristic hardfaced layer zones is described elsewehere, /16/.

Table 1. Chemical composition and labelling for 55CrMo 8 and X27CrMoV 51.

EN	Chemical composition, %									Relation to other standards	
	C	Si	Mn	P	S	Cr	Ni	Mo	V	DIN	UNI
55CrMo 8	0.55	0.3	0.7	0.035	0.035	1.1	1.7	0.5	0.12	56NiCrMoV7	U52NiCrMo6KU
X27CrMoV 51	0.40	1.0	0.4	0.025	0.025	5.0	-	1.3	0.4	X38CrMoV5	UX35CrMo05KU

Table 2. Mechanical properties and microstructure 55CrMo 8 and X27CrMoV 51.

EN	Soft annealing			Tempering			Preheating temperature (°C)	Microstructure, base metal (BM)
	T (°C)	HV_{max}	R_m (MPa)	t (°C)	HRC	R_m (MPa)		
55CrMo 8	670-700	250	850	400-700	50-30	1700-1100	≈ 300	M + B (interphase)
X27CrMoV 51	800-830	250	850	550-700	50-30	1700-1100	≈ 300	M + B (interphase)

DEVICE AND RESULTS FOR SHEAR TESTING

In order to check the shear resistance between the hardfaced layer and the substrate, for determining the shear strength of BM, a special tool that enables an estimate of absolute and relative bearing capacities of characteristic cross-sections (Fig. 1) is designed and mounted on an universal mechanical testing machine (Fig. 2).

After test tubes have been prepared by grinding, polishing and etching, experiments are carried out with the aim to determine the shear resistance between the hardfaced layer and the base metal (BM) and the shear strength of the base metal itself. Diagrams showing shear force vs. shear strain for some characteristic test tubes are shown in Fig. 3.

Table 3 gives experimentally determined shear strengths for the theoretical interface between the BM and the hardfaced layer. Some of the mechanical characteristics of the base metal are taken from catalogues, /19/, where: HRC stands for hardness, $R_m = k \cdot HB$ denotes the tensile strength as a product of factor k and Brinell hardness, while the shear equation is determined experimentally, Table 4.

Table 5 and Figs. 4a and 4b show that the shear resistance of the interface that separates the hardfaced layer and the BM generally exceeds the shear resistance of the BM, which means that the applied repair technology with preheating, and post-weld heat treatment, gives optimal results in rebuilding of hot work steels. Furthermore, studying and analysing the obtained results, shown in Table 4, draws a conclusion that factor k varies in the range: k = 0.60–0.70 for Č5742, i.e. k = 0.53–0.73 for Č4751, which means that the mean values of this factor are: k_{sr} = 0.67 for Č5742 and k_{sr} = 0.63 for Č4751.

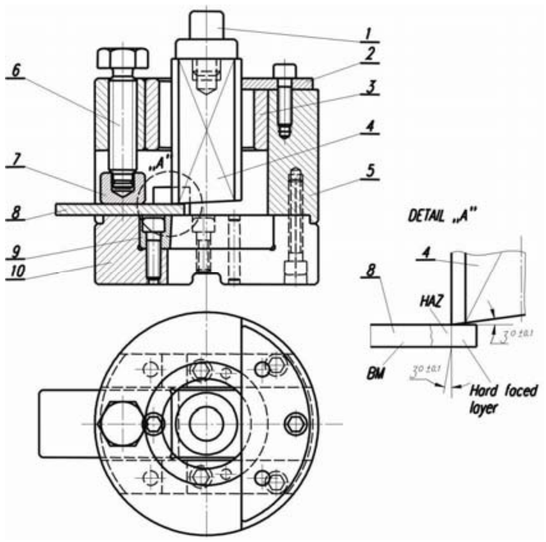


Figure 1. Drawing of tool used to test shear strength, /14/: 1-reducer, 2-limiter, 3-guide, 4-punch, 5-tool body, 6-tightener, 7-pad, 8-specimen, 9-support plate, 10-lower part of the tool.

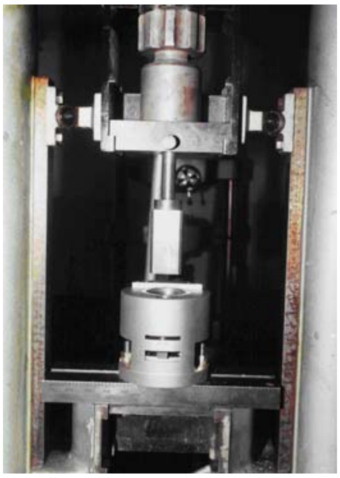


Figure 2. Photo of testing equipment

Table 3. Shear strength between hardfaced layer and BM.

Test tube labell – BM FM-Number of layers	Max. force F_m (N)	Cross-section S_o (mm^2)	$\tau_M = F_m/S_o$ (MPa)
9.1-Č5742-UTOP 38-2	63000	82.2	766
11.1-Č5742-UTOP 55-3	91000	82.2	1107
13.1-Č5742-UTOP 38-3	125000	82.2	1521
15.1-Č5742-UTOP 55-2	105000	82.2	1277
10.1-Č4751-UTOP 55-3	85600	82.2	1041
12.1-Č4751-UTOP 38-2	95400	82.2	1161
14.1-Č4751-UTOP 55- 2	71800	82.2	873
16.1-Č4751-UTOP 38-3	71400	82.2	869

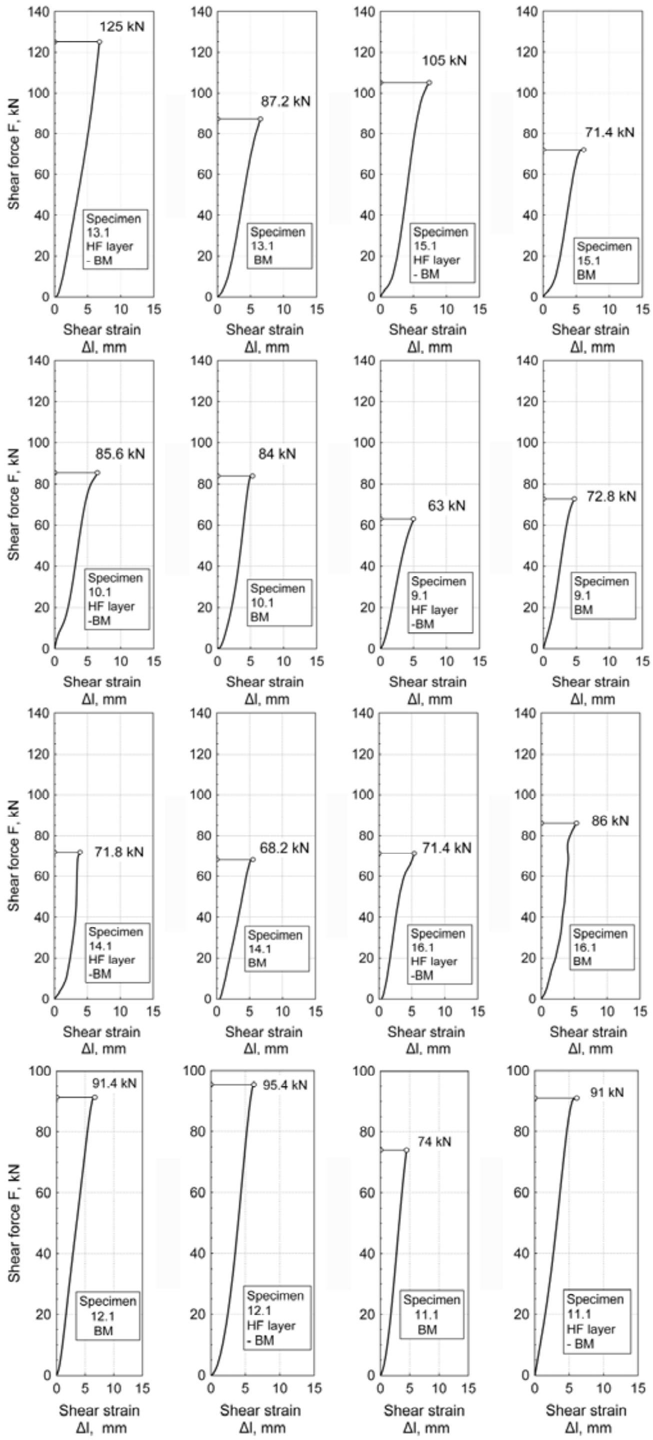
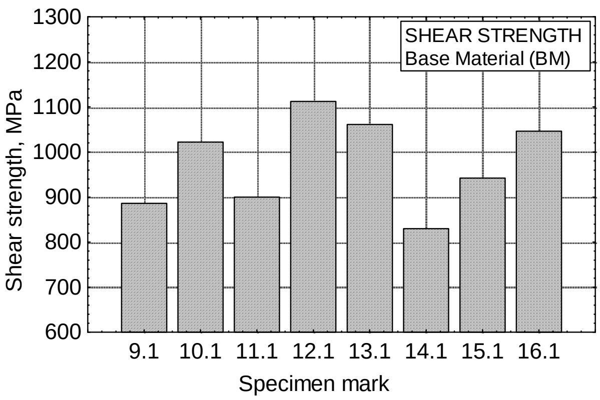


Figure 3. Shear force between hardfaced layer and BM and the shear force of the BM.

Table 4. Relation between tensile and shear strength of steels 55CrMo 8 and X27CrMoV 51.

Test-tube mark	Materials	Hardness BM HRC	Tensile strength R_m (MPa)	Shear strength τ_m (MPa)	Factor $k = \tau_m/R_m$	k_{sr}
9.1	Č5742	40-46	1260-1485	886	0.60-0.70	0.67
11.1	Č5742	44-44.5	1400-1420	900	0.63-0.64	
13.1	Č5742	43-46.5	1360-1508	1070	0.70-0.78	
15.1	Č5742	44.5-45.0	1420-1440	942	0.65-0.66	
10.1	Č4751	43.4-45	1404-1459	1022	0.70-0.73	0.63
12.1	Č4751	53	1850	1112	0.60	
14.1	Č4751	44-47.5	1422-1551	830	0.53-0.58	
16.1	Č4751	48.5	1598	1046	0.65	

a) 

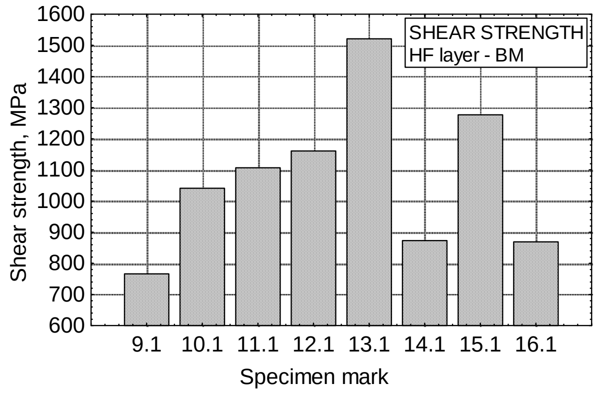
b) 

Figure 4. Shear strength values: a) base metal, b) base metal – hardfaced layer.

CONCLUSION

Based on theoretical and experimental investigations conducted in this paper, the following conclusions are drawn:

- By designing and manufacturing the original tool for shear it was possible to determine the shear strength, both for base metal and certain zones of the hardfaced layers.
- It was proven that the shear resistance of the hardfaced layers' certain zones, especially of the HAZ, surpasses the shear strength of the base metal several times, pointing to the validity of the applied repair hard-facing technology.
- With the tool for shear, the ratio of tensile and shear strength (k) was also checked, since the precisely determined value of this ratio can be useful in forging die design, and because in literature one can find values of this coefficient varrying in a very wide range.

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