XVII Konferencja Naukowo-Techniczna
TKI2024
TECHNIKI KOMPUTEROWE W INŻYNIERII
15–18 października 2024

Impact resistance of a welded joint of high-strength steel as a result of firing with 7.62×39 mm rounds designed for AKM type assault rifles and their derivatives

Martyna Zemlik[1], Łukasz Konat[1], Kayode Olaleye[2], Krzysztof Jamroziak[2]
[1]Katedra Inżynierii Pojazdów, Politechnika Wrocławska
[2]Katedra Mechaniki, Inżynierii Materiałowej i Biomedycznej, Politechnika Wrocławska
email: martyna.zemlik@pwr.edu.pl, lukasz.konat@pwr.edu.pl, kayode.olaleye@pwr.edu.pl, krzysztof.jamroziak@pwr.edu.pl

SUMMARY: As a result of performed welding processes, steels with increased hardenability experience negative microstructural changes, resulting in a sharp decrease in mechanical properties in the zone of the welding material and in the heat-affected zone. Due to the limited R_m strength of commercially available welding consumables, in many cases not exceeding a value of 1000 MPa, the reduction in mechanical properties can reach up to 60% for steels with a hardness of 600 HBW. The group of materials characterized by the highest mechanical strength indices includes boron martensitic steels, which are used for components subjected to abrasive wear, as well as ballistic shielding. Accordingly, it should be concluded that as a result of the carried out welding techniques, the functional properties of the discussed group of metallic materials of the welded joint do not correspond to the required ballistic resistance, characteristic of the zone of the base material. It is possible to achieve the highest indices of mechanical strength in this zone only as a result of the use of advanced welding techniques, high-quality welding materials and by means of subsequent heat treatment. This paper presents the results of tests on the resistance to loads of a dynamic nature of welded joints of Hardox 450 steel. In the course of the work carried out, it was shown that with the use of intermediate round 7.62×39 mm nb. wz. 43 with PS projectile, when firing from a distance of 10 m, a minimum sheet thickness of 5 mm ensures the preservation of material continuity in all characteristic zones of the welded joint.
KEYWORDS: martensitic steel, heat treatment, SAW welding, ballistic resistance

1. Introduction

Due to their high mechanical and plastic properties, low-alloy boron martensitic steels are the leading metallic material used for ballistic shielding [1]. Although manufacturers do not provide data on the strength properties of higher grade steels, i.e. Armox Advance or Mars 650, on the basis of studies considering similar grade steels like Hardox 600 and Hardox Extreme, it can be concluded that their strength R_m exceeds the value of 2000 MPa [2, 3]. It should be noted that the above steels are also characterized by low content of harmful elements, fine-grained structure, satisfactory plastic indices, and as a result, they can be successfully used as an alternative to armored steels. Parts of armored vehicles are joined together mainly by welding techniques. However, the solutions proposed by steel manufacturers, including the use of dedicated welding materials, are insufficient in terms of machine efficiency and performance. A study of the effect of using different welding materials on mechanical properties was conducted in [4]. It was observed that the R_m strength of the joint made of low hydrogen ferritic (LHF) and austenitic (ASS) alloy was 41.7 and 30.6% of the value of the base material, respectively, while the impact strength of the austenitic joint was found to be 20% higher than that of Armox 500T steel. However, in the area of the welded joint there is a so-called microstructural notch, manifested by a decrease in mechanical properties by as much as 50%. Softening of the material is a widely analyzed issue in the welding of high-strength materials, and only through the use of advanced technologies and subsequent heat treatment [2], the highest strength indicators can be obtained. The purpose of this study is to verify the impact resistance of welded joints of Hardox 450 steels subjected to comprehensive heat treatment.

2. Methods and Materials

Hardox 450 steel sheets with a thickness of 10 mm were used for the study, which were joined by a double-sided butt weld using submerged arc welding (SAW) technology. The material was then subjected to comprehensive heat treatment, taking into account normalizing and hardening processes.

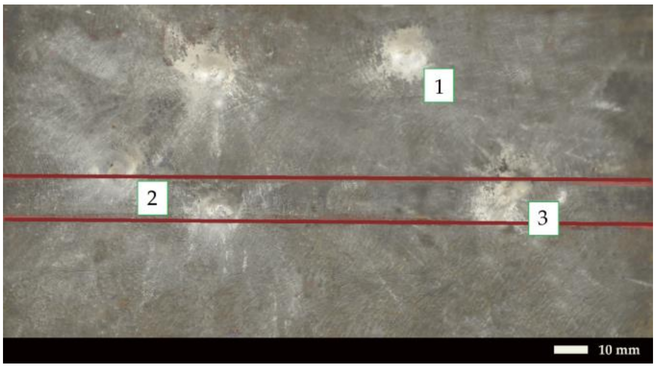

Fig. 1. Macroscopic image of the sheet surface of the welded joint of 5 mm thick Hardox 450 steel in heat-treated state after ballistic impact. Front side. In all cases, material continuity was preserved. The red lines delimit approximately the area of the welded joint

In order to eliminate variables taking into account the geometric notch and thickness of the component, the sheet was abraded to a minimum sheet thickness of 4 and 5 mm [5]. Then, the test material was fired on a ballistic track in accordance with PN EN 1522 standard with intermediate ammunition with a 7.62×39 mm nb. wz. 43 PS bullet. The effects of firing the samples are illustrated in the following macroscopic photo (Figure 1).

3. Assumptions and simulations

Based on the geometry of the projectile, numerical models were developed [6]. The following components were included in the model (Figure 2).

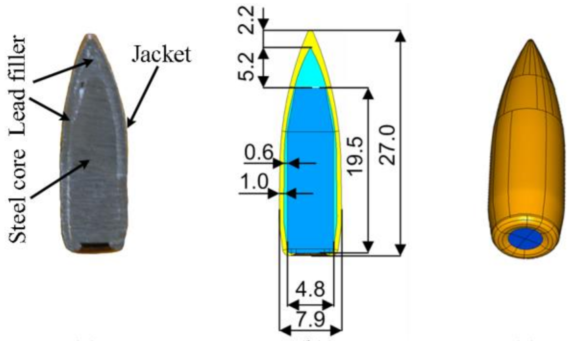

Fig. 2. Models of the projectile 7.62×39 mm wz. 43 with PS: (a) projectile structure, (b) geometric dimensions, (c) geometric model

The initial velocity of the projectile was assumed to be 715 m/s and the mass of the projectile 7.9 g. Discretization of the projectile and the casing material including the weld was carried out with Tetra-type solid finite elements of 1.0-2.0 mm. Nonlinear dynamic analysis was performed using Abaqus/Explicit software. For discrete models, the Johnson-Cook material model was used. For the purpose of reflecting the discontinuity of the structure caused by material rupture, boundary strain (ε_{gr}) was introduced as a fracture mechanics parameter. Boundary strain was determined for 3 material zones: base material zone, heat-affected zone, welded joint zone. In the case of a heat-treated specimen, one heat-treatment compound deformation was determined for the entire material volume. The adopted material data are summarized in Table 1. An example of the results of the numerical analysis is shown in Figure 3.

Table 1. Material constants

Material	E [GPa]	ν [-]	A [MPa]	B [MPa]	m [-]	n [-]
Core (St45)	210	0.32	430	820	1.03	0.3
Jacket	210	0.20	350	420	1.03	0.3
Lead filler	16	0.42	5.15	3.5	1.03	0.5
Weld no HT	210	0.32	677	680	1.0	0.3
Weld with HT	210	0.30	1350	1362	1.0	1.0

Where: HT - heat treatment, E - Young's modulus; ν - Poisson's ratio; A - yield at zero plastic strain; B - hardening constant; m - temperature softening constant; n - hardening exponent.

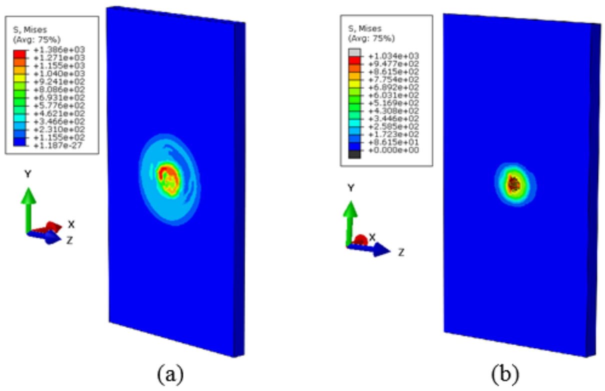

Fig. 3. Results of FEM: (a) heat-treated state, (b) as-welded state

4. Discussion and results

Hardox 450 steel with a sheet thickness of 5 mm retains material continuity already within 20 mm from the zone of the alloying material as a result of firing a 7.62×39 mm nb. wz. 43 PS bullet, but due to the presence of a structural notch, complete penetration in the welded joint zone occurs in each case. In the case of the heat-treated condition, the assured projectile is stopped (Fig. 1).

Similar results are observed in the simulation (Fig. 3b), where the local work field is small, as evidenced by the fact that the pressure under the penetrating projectile causes the material to be knocked out in the shape of a plug. As shown, an important element is a weld with adequate strength characteristics, adequately similar to the base material, joined together by welding techniques.

Calculations have been carried out in Wroclaw Centre for Networking and Supercomputing (http://www.wcss.pl), grant No. 452.

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