WYMAGANIA STAWIANE ZĘBOM CZERPAKÓW KOPAREK WIELONACZYNIOWYCH KOŁOWYCH EKSPLOATOWANYCH W UTWORACH TRUDNO URABIALNYCH

REQUIREMENTS FOR BUCKET WHEEL EXCAVATOR TEETH OPERATING IN HARD MINEABLE SOILS

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Przedstawiono specyfikę zużycia zębów czerpaków do koparek wielonaczyniowych kołowych eksploatowanych w utworach trudno urabialnych. Zaprezentowano wyniki badań modelowych różnych rodzajów zębów na stanowiskach doświadczalnych. Podano zasadę samoostrzenia się zębów i wynikające stąd korzyści. Zamieszczono sposoby montażu zębów na narożach czerpaków. Opisano stosowane technologie wytwarzania zębów. Zaprezentowano wykaz wymagań jakie powinny spełniać zęby czerpaków do koparek wielonaczyniowych kołowych eksploatowanych w utworach trudno urabialnych.

Słowa kluczowe: *koparki wielonaczyniowe kołowe, utwory trudno urabialne, zęby czerpaków, badania modelowe, opory urabiania, technologia wytwarzania, wymagania*

The wear of teeth in bucket wheel excavators (BWE) operating in hard mineable soils has been presented. Results of model tests of different types of teeth carried out on experimental stands have been discussed. The rule of teeth self – sharpening and resulting benefits have been shown. Methods of teeth assembly on bucket knives have been presented. Also technologies of bucket teeth manufacturing have been described. List of requirements for bucket teeth which should be met by BWEs operating in hard mineable soils has been presented.

Keywords: *bucket wheel excavators (BWE), hard mineable soils, bucket teeth, model tests, cutting resistances, manufacturing technology, requirements*

Introduction

As it was presented and justified in [1], buckets of excavators intended for operation in hardly-workable grounds are to be mandatorily provided with teeth, and apart from their shape also the angles of positioning the teeth on the knife, their number and way of mounting on the knife and their manufacturing technology are of importance.

The value of tool thrust force Fs depends not only on the properties of the formation subjecting to cutting, but also on the cutting angle as these values are decisive for the position and dimensions of the slip area where the limiting state was attained. Basing on the results of experimental studies, Fig. 1 shows the relationship between the cutting resistance for wedge-shaped tool and the cutting angle δ. The diagrams show that the cutting resistance rises along with the increase of the cutting angle. This rise is relatively low, somewhat 1% for small angles, but after the cutting angle exceeds about 50^o, the rise is up to 7% per one degree change of the cutting angle.

Model tests on experimental stands

A series of issues related to the influence of tooth shape on the excavation process are explained by model tests on experimental stands [4][5][6][7].

Tests were run for various types of teeth, including wedge--shaped, prismatic, pyramid, of separate geometrical forms (Figs. 2, 3). The main research conclusions resulting from the tests can be expressed as follows:

- While cutting cohesive formations with tendency to fragile fracture, the best results, as concerns the efficiency of loosening, are attained for the B2 tooth, i.e. that of the pyramid shape with symmetric trapezium base. The pyramid shape of the cutting edge is composed of the wedges with the angles β, β_1, β_2 (Fig. 2a). The main wedge with the angle β (cutting edge angle) causes loosening a slice from the ground. Within some range, this process is supported by the action of wedge with the angle β_2 which causes side fractures. In turn, the wedge with angle β_1 generates fractures above the tool thrust surface (inclined to the cutting material surface at the angle $\delta = \alpha + \beta$). Inclination of side surfaces of the tooth with respect to the thrust surface at the angle β_1 reduces also side pressure on the tooth.

The cutting edge angle β in the pyramid tooth should, theoretically, be as low as possible, but due to strength reasons and abrasive wear, its value should generally amount to $\beta = 24 \div 30°$.

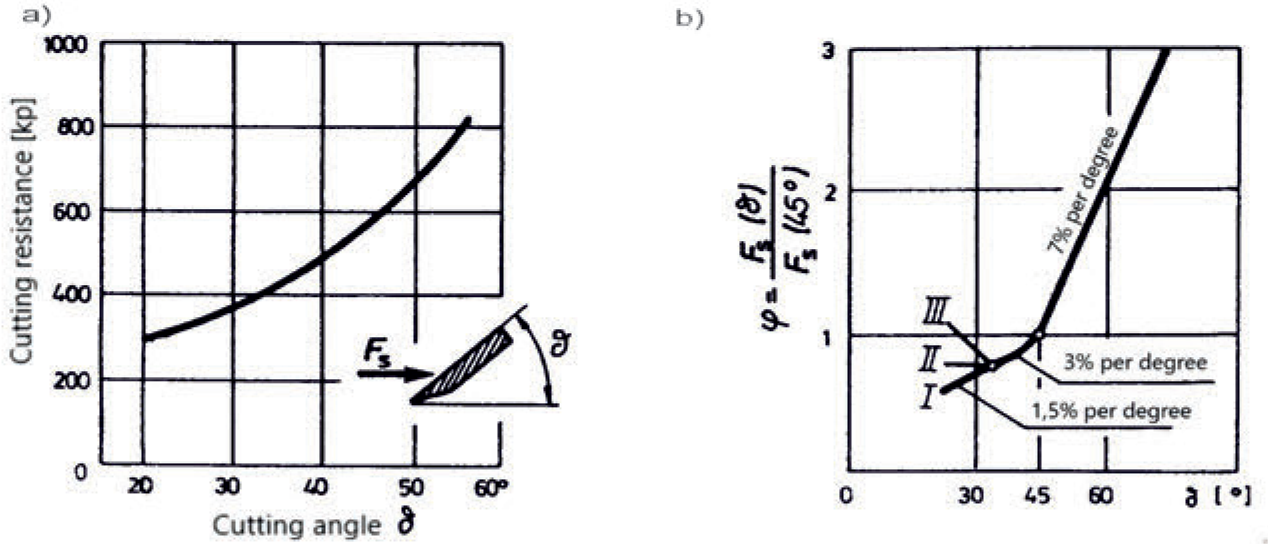

Fig. 1. Cutting resistance versus cutting angle δ: a) acc. to [2], b) acc. to [3]
Rys. 1. Zależność oporu urabiania od kata skrawania δ: a) według [2], b) według [3]
LEGENDA - Cutting resistance = opór urabiania; cutting angle = kąt skrawania; per degree = na stopień;

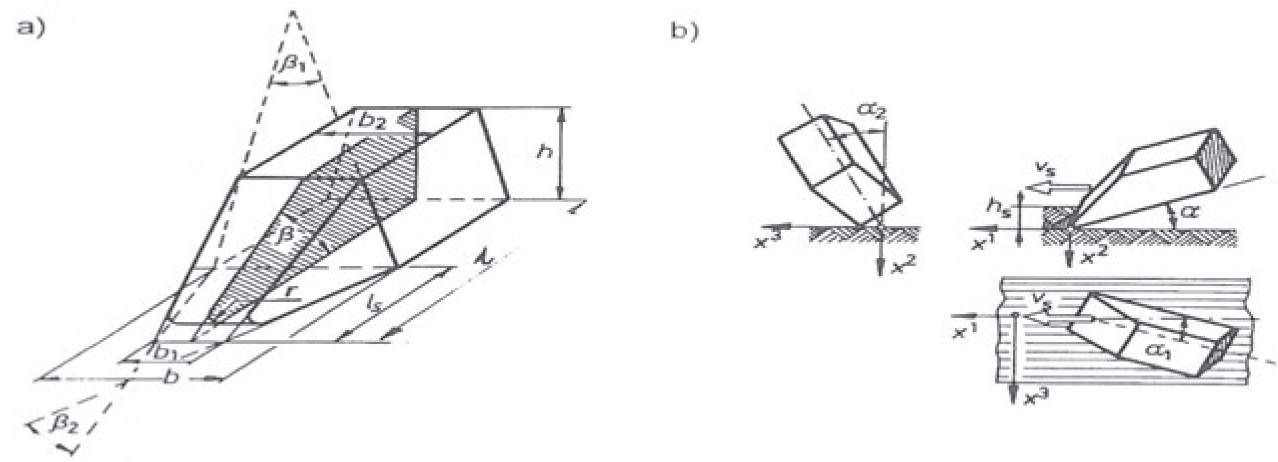

Fig. 2. Geometry of teeth used in tests: [4]
a) geometrical parameters of teeth,
b) technological angles of teeth (determined during tests).
Rys. 2. Oznaczenie geometrii zębów użytych do badań [4]
a) parametry geometryczne zębów
b) kąty technologiczne zębów (ustalone w toku badań)

- As a result of serious abrasive wear of tooth (when its linear shortening amounts more than about 20% of the length of the edge part l_s), some additional, very disadvantageous resistance area is generated on its face, inclined at the angle ε to the tooth flank, generating the effect of edge passive pressure on the cutting surface (Fig. 4). Passive area for various teeth made of the same material and subjecting to the same type of processing to improve their strength and abrasion resistance properties, is generated the fastest for the group of pyramid teeth C, then in prismatic teeth B. The highest durability as concerns their abrasive wear demonstrate the wedge teeth A.

- The optimum value of the clearance angle α takes the value α = 15÷18°, which – together with the edge angle β = 24÷30°, provides the following nominal range of variations for the cutting angle $\delta(\beta+\alpha)$ δ = 39÷48°, while the limiting value of this angle should not exceed $\delta = \delta_{gr} = 55°$.

- The tooth should be of appropriate high bending strength and have high resistance to cutting forces and abrasive wear.

- The tooth should be of low tendency to fragile fractures and chip ping, high impact resistance and resistance to unit pressure (especially in the vertex area).

The tooth self-sharpening process

On account of a change in tooth shape, which takes place especially intensely for operations in hardly-workable formations with large amount of abrasive fractions, which in turn generates high cutting resistance due to formation of passive pressure surface, it is of very importance that the tooth be relatively resistant to this disadvantageous phenomenon. Such resistance can be reached when the tooth, over a length of its expected abrasive wear, has approximately constant thickness and a given initial contact area (of superficial type) tangential to

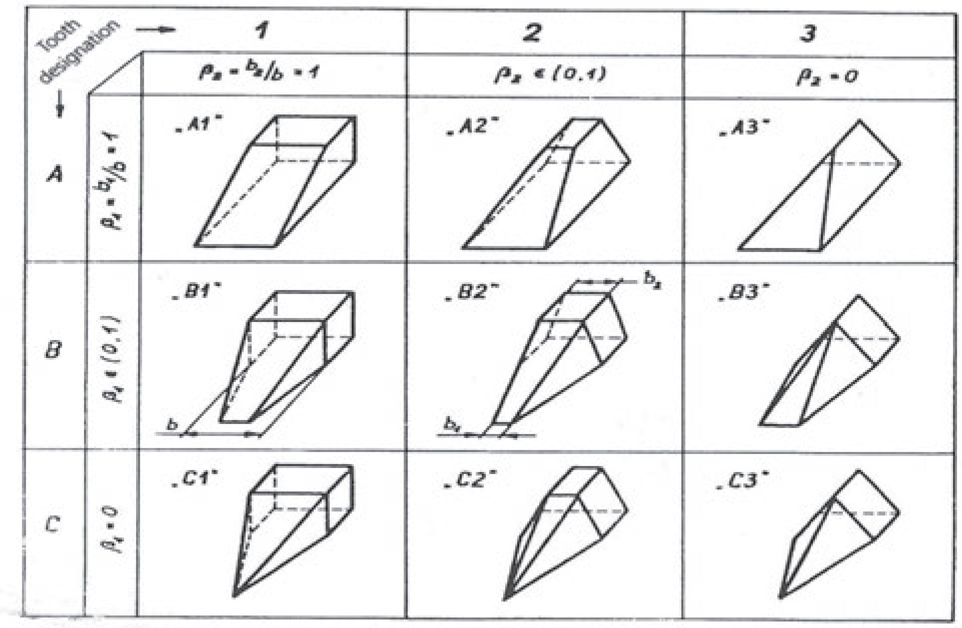

Fig. 3. Geometric forms of teeth used in experimental analysis of their working mechanism in model materials imagining the properties of hardly-workable cohesive rocks; tooth designation: [4] A – wedge-shaped teeth, B – prismatic teeth, C – pyramid teeth
Rys. 3. Geometryczne formy zębów użytych w toku eksperymentalnej analizy ich mechanizmu pracy w modelowych materiałach odwzorowujących cechy trudno urabialnych skał zwięzłych, oznaczenie zębów: [4] A – zęby klinowe, B – zęby pryzmatyczne, C – zęby ostrosłupowe
LEGENDA - Tooth designation = oznaczenie zęba

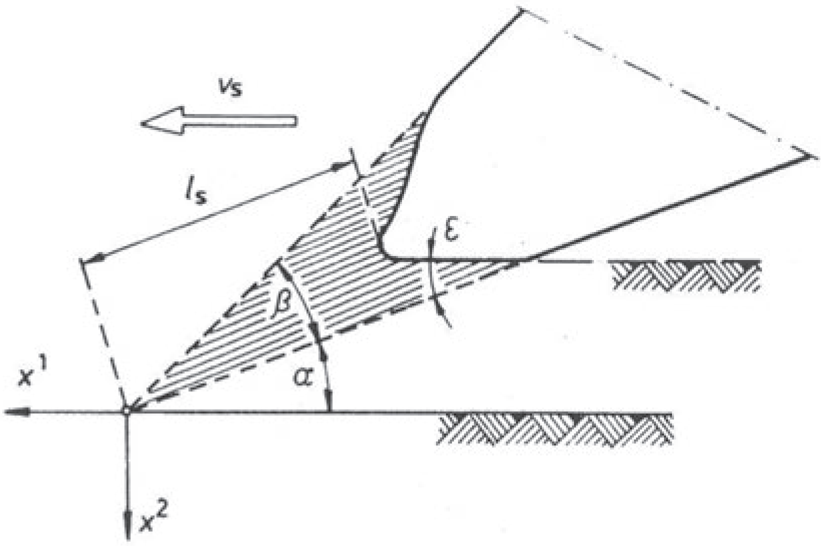

Fig. 4. Mechanism of creating the passive pressure surface caused by serious abrasive wear of the tooth [4]
Rys. 4. Mechanizm formowania powierzchni odporowej w wyniku zaawansowanego zużycia zęba [4]

the cutting path will be formed, so the process called self-sharpening the tooth takes place (Figs. 5, 6). The self-sharpening process can be initiated not only by appropriate shape of the tooth, but also by proper angles of positioning the tooth on the bucket knife. These angles can be found from computer analysis for each type of the tooth and bucket and cutting parameters of a specific excavator [8] [9]. The fundamental issue is the kinetics of cooperating the teeth with the rock being cut, expressed by vectorial velocity of the formation with respect of teeth during cutting. To analyze this cooperation, we need precise knowledge about component vectors of body velocity in coordinate systems related to particular walls of the tooth cutting edge for:

- all teeth on the bucket,
- various rotary speeds of the excavator body,
- various positions of the mining boom,
- various positions of the bucket on the bucket wheel.

This allows to determine, for each tooth, the numerical values of the main cutting parameters, such as tool rake and clearance angles, and to state the existence of other phenomena affecting the digging forces. For instance, an unwanted phenomenon is existence of formation component speed perpendicular to the wall plane and directed to the interior of tooth (except the rake wall where it is natural), which takes place in case this wall is pushed into the formation (like for the negative clearance angle), which causes a considerable increase of cutting resistance. This is also of negative effect for tooth wear. This hardly be attained at side walls of the tooth as they are usually parallel and the components perpendicular of body velocity have opposite signs on them, and the values change along with body rotational speed. This adverse phenomenon can be however minimized by proper positioning the teeth on the bucket.

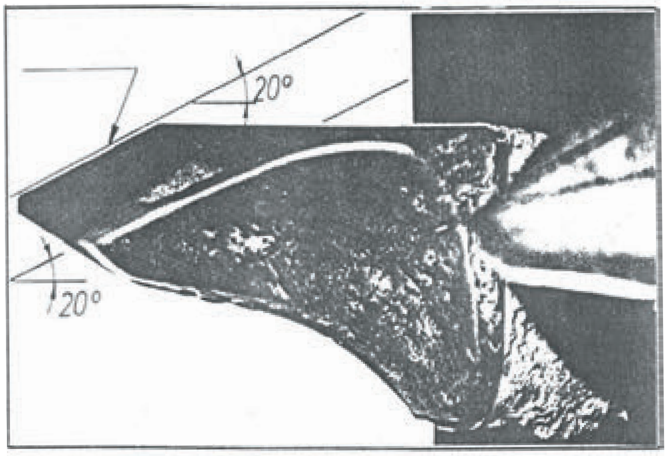

Fig. 5. Principle of self-sharpening the tooth
Rys. 5. Zasada samoostrzenia zęba

Fig. 6. Wedge-shaped pad welded self-sharpening tooth worn out
Rys. 6. Ząb o kształcie klina prostego napawanych samoostrzący się po zużyciu

The number of teeth and a way to assembly them on the bucket knife

As concerns the number of teeth on the knife, it is assumed that higher number of teeth is advantageous for hardly-workable grounds. It reduces the knife edge between teeth, thus protects the knife against fast wear, and also reduces dynamic loads while the bucket goes in and out the ground being mined. For grounds of especially high cutting resistances, the number of teeth can be so high that they cover almost the full surface of the knife (Fig. 7) [10].

For hardly-workable grounds where, as aforementioned, a fast wear of teeth and buckets takes place, most of operating costs refer to their replacement. In case of teeth with permanent fastening, welded to the knife, their replacement makes it necessary to dismount the buckets, to transport them to overhaul workshops, to retransport and to mount them on excavator. Hence, for hardly-workable grounds, the teeth with such type of fastening, which allows their fast replacement without the need to dismount the bucket shall be applied. To this purpose, special pocket are welded to the bucket to fasten the teeth (Fig.8). The fastening must enable fast and secure mounting and dismounting the tooth and it should be resistant to various kinds of contamination. In practice, the tooth is fastened in the pocket using special wedges, bolts, etc. In recent years a new fastening was developed using special locks enabling very fast and secure mounting and dismounting the teeth (Fig. 9) [11].

Fig. 7. Bucket of BWE KWK 1200 with increased number of teeth [10]
Rys. 7. Czerpak koparki wielonaczyniowej kołowej KWK 1200 ze zwiększoną liczbą zębów [10]

Fig. 8. View of the bucket of BWE KWK 1500 with replaceable teeth fastened in the pocket with bolts (pocket welded into the knife)
Rys. 8. Widok czerpaka koparki wielonaczyniowej kołowej KWK 1500 z zębami wymiennymi mocowanymi w oprawach za pomocą sworzni (oprawy wspawane do noża)

Fig. 9. Tooth manufactured by Esco with the pocket, with lock for fast mounting [13]
Rys. 9. Ząb firmy Esco z oprawą z szybkim mocowaniem w postaci zamka

Fig. 10. Wedge-shaped casted replaceable tooth manufactured by Legmet, prior to wear
Rys. 10. Ząb o kształcie klina wymienny odlewany produkcji Legmet, przed zużyciem

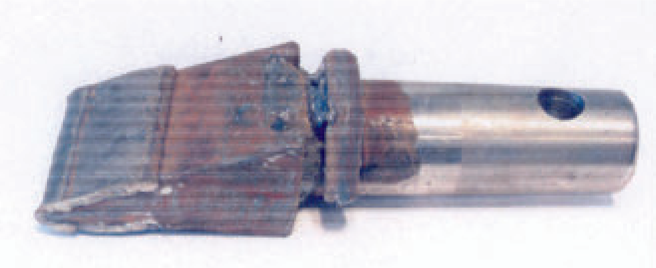

Fig. 11. Wedge-shaped surfaced by welding replaceable tooth, prior to wear
Rys. 11. Ząb o kształcie klina wymienny napawany przed zużyciem

Teeth manufacturing technologies

Two technology types are used to manufacture teeth for excavator buckets:

a) Teeth are the castings made totally out of abrasion-resistant materials and then subjected to specialized heat treatment to get required hardness (Fig. 10). The alloy cast steels, L 35 GSM, L 30 GS, L 35 HM, are most often used.

b) Teeth are made out of materials which are not sufficiently resistant to abrasion, and then their cutting edge part is hardened (Fig. 11). Materials generally used are the carbon steel, grades S235JR, S275JR, or low-alloy constructional steel, grades S355J0, S355J2. The cutting edges are hardened mainly by padding with powder wires, such as used for padding the surfaces of knives [12]. Apart from padding welds, other technologies are also used like metal spraying, reinforcing the cutting edge part with various inserts with materials of very high hardness, hence the resistant to abrasion. In domestic lignite mines, both technologies of teeth manufacturing are used for hardly-workable formations, whereby:

- for grounds featuring heavy abrasive properties but without or with small amount of not workable inclusions, more suitable are the teeth made with the „b)" technology as the hardness of pad welded teeth can be much higher than that of the casted teeth,

- for grounds featuring heavy abrasive properties and also including large amount of hard rock inclusions, more suitable are the teeth made with the „a)" method as due to hits of teeth against rock, the padding weld or hard inserts in the edge part are chipped away or broken down, so then the teeth wear process proceeds very rapidly. However, the last years brought large progress in development of powder wires allowing to get padded weld of high abrasive resistance and relatively good impact resistance, but in grounds of the IV-V class of workability with large amount of stones appearing in domestic lignite mines, the impact resistance of these pad welds is insufficient [12].

Furthermore, both aforementioned technologies should enable teeth production in large lots using specially arranged automated production lines to get relatively low manufacturing costs and a given and repeatable quality level [12].

Summary

To sum up the above description the teeth intended for excavation the hard mineable soils should:

- be shaped and positioned on the bucket knife so as to get the self-sharpening process for the whole range of their wear,

- the cutting edge angle β should be as low as possible, however due to strength aspects and also abrasive wear, it should be within the range 24°÷30°,

- the tooth clearance angle α should be within 15°÷18°, so together with the tool angle β amounts to the cutting angle δ= 39°÷48°, and the limiting value of this angle should not exceed 55°,

- the tooth should feature high resistance to abrasive wear on its face and clearance surface, and it also should have high impact resistance in this zone to eliminate break and point chips when encountering hard inclusions, interlayers, etc.,

- the tooth should feature appropriate high bending strength and resistance to cutting forces, selected to be the weakest element of the bucket and to protect it and other excavator assemblies against excessive impact loads,

- the way in which a tooth is fastened in the pocket should ensure its fast and easy mounting/dismounting directly on excavator, and stable settlement,

- the number of teeth on the bucket should be relatively high to protect the bucket knife against wear; this also reduces dynamic loads generated when the bucket goes in and out of the excavated ground,

- the tooth should be as light as possible so as it can be mounted and dismounted by excavator crew,

- the technology used to manufacture the teeth should depend on the kind of excavated ground: for grounds with high abrasive properties but without or with a small number of hard non-workable inclusions, more suitable is the technology using the materials without special resistance to abrasion and hardening the cutting edges by applying very hard metallic coatings. For grounds with high abrasive properties including also large number of hard inclusions and intelayers, more suitable is the technology consisting in casting the whole teeth out of abrasion-resistant materials which then subject to specialized heat treatment.

- the technology of teeth production (independently of its type) should enable production of large series using specialize automated production lines to ensure relatively low production costs and repeatable quality,

- for hardly-workable grounds, instead of teeth there can be used bucket corners which have both advantages and disadvantages. The advantages include much higher strength and durability than those of teeth, while disadvantages consist in high cutting resistances just after small wear, much higher than those for self-sharpening teeth; furthermore, strong corners do not provide such protection as teeth for mining system and supporting structure against effects of excessive impact loads.

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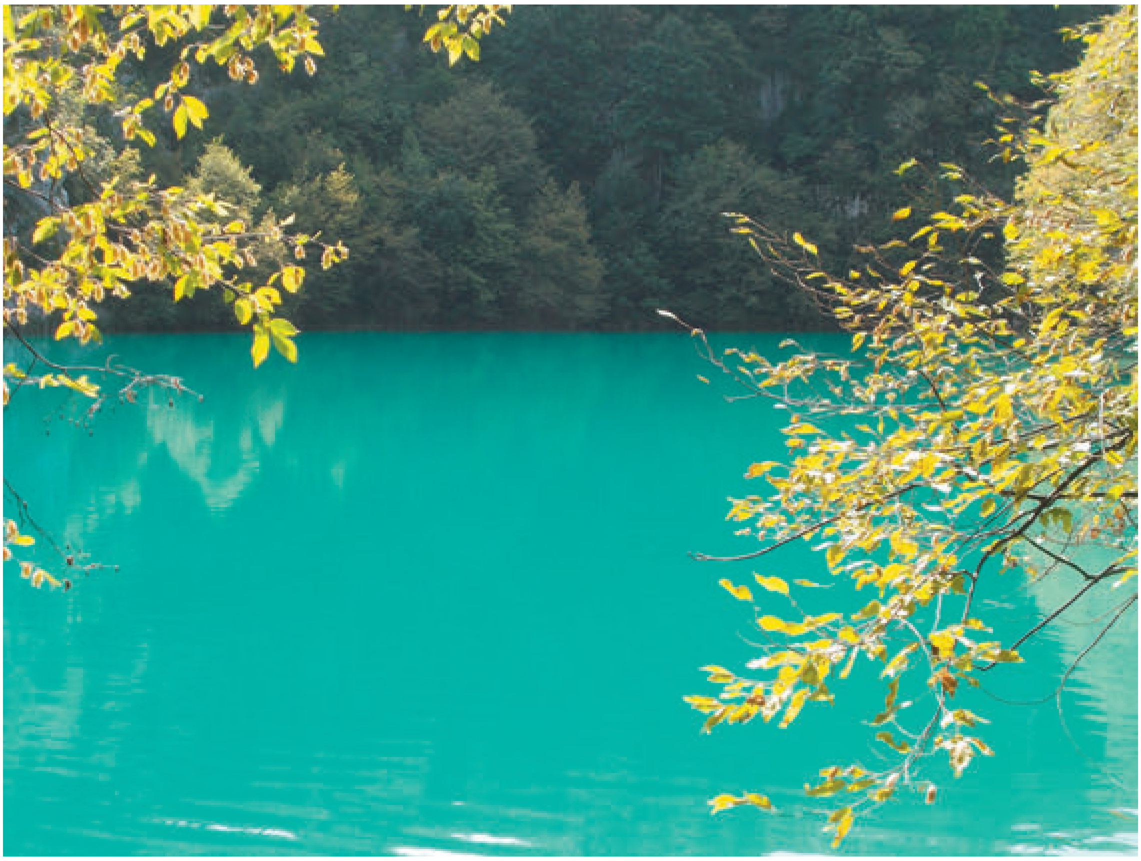

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