# INFLUENCE OF DEPIGMENTATION ON MECHANICAL PARAMETERS OF HORSEHAIR OF OLD KLADRUBER HORSE

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**Abstract**
For groups of black and white hairs of Old Kladruber grey horse stress-strain curves have been measured and subjected to a multi-parameter analysis. A total of 15 material and mechanical parameters have been taken for each hair analysed. Both groups have been compared statistically, with an unexpected result. Discoloured hairs gain higher values in three parameters than hairs of still un-discoloured foals. They also have lower variance than the hairs from the group of young, still pigmented horses.

**Key words:** stress, strain, deformation, curve, mechanical properties, elasticity.

## INTRODUCTION

Most dark polymers have considerably different and mostly better mechanical parameters than light ones due to higher carbon content. Biopolymers make no exception, as shows a whole number of prior works. Elasticity module, extensibility, ultimate stress and yield strength increase significantly with colour deepness. This fact holds both for human hair and porcupine spines as well as guinea pig or ferret hair, and holds for horsehair also. Up to now, these mechanical parameters have been measured for non-discolouring individuals only – see e.g. ŠIMKOVÁ ET AL. (2013). Most species have their colour fixed from the moment of reaching adult age.

For these reasons, we have decided to find whether aforesaid characteristics manifest in the discolouring species also. We have opted for horsehair of the grey form of Old Kladruber horse.

Old Kladruber horse, belonging to the group of western horses, whose predecessor was Equus robustus, developed together with the Spanish breed under the influence of Arab-Berber blood. It's a typical carriage horse; its history in the Czech lands extends to the year 1579 when Holy Roman Emperor Rudolf II promoted the imperial park to a horse-breeding farm. It is ranked among 4 breeds registered in genic resources of the Czech Republic. It is our only live national cultural monument. Leading Czech hippologist Prof. František Bílek was responsible for the regeneration of Old Kladruber black horse. Genetic relationship between grey and black Kladruber horses is low, as each colour has been bred autonomously in the history – see PŘIBYL ET AL. (1997). The black and grey varieties differ slightly in some traits;the conformation of the grey variety corresponds more to the breeding goal (JAKUBEC ET AL., 2007).

Old Kladruber grey horse is black colour both coat and horsehair up to the age of 1–5 years (according to the lineage); after reaching this age they change their colour completely to a white one over the whole body surface relatively quickly, generally through two moultings. Question therefore arises, whether and how do mechanical parameters of these discoloured hairs change compared to the original ones.

Following mechanical and material parameters of the hairs have been determined for testing:

Hair diameter, engineering module of elasticity, true module of elasticity, nominal linearity limit, yield strength, ultimate stress, true ultimate stress, length at rupture, fracture strain, true relative elongation to rupture, total mechanical work necessary to break the hair, toughness and resilience.

All these parameters have been compared between the black and the white hairs of Kladruber horses.

**Fig. 1.** – A grey („white“) mare with a black foal. Photo: Dalibor Gregor

A load curve is divided into three parts (see Fig. 2):

- First part – elastic (1) – the part where the deformation is small enough for the sample to return to its original shape and dimension if external forces cease to affect it. In the case of hair it contains Hook area (1a) where tension is directly proportional to deformation. By a constant of this proportionality and therefore the slope of the line Young's modulus is determined. The rest of this part is non-linear (1b) and ends by yield strength (A), by which the maximum elastic deformation is defined. Deformations beyond this point of the curve are already plastic; after application of such external force the sample remains permanently deformed. At that point the stress-strain curve passes into the plastic deformation area.

Starting moment of the deformation is determined from the equation of the line interpolating the stress-strain curve in the Hook area. The constant in this equation determines the intersection of the line with the axis of deformation. We move all the deformation data observed on the deformation curve backwards by this value.

- The second part (2) where irreversible changes already take place in the sample and where even application of a constant force may lead to increasing deformation, simply put the area beyond yield strength, is characterized by viscoplastic deformation. The shape of the curve in this area is greatly influenced by the deformation speed and at higher speeds (from 10 %/min up for hair), the start of that second phase may be characterized by a negative slope.

- Third part (3) is the area of reinforcement before rupture where the slope of the breaking curve increases again (B). Steady increase in tension leads to rupture of the sample (BENZARTI ET AL., 2011).

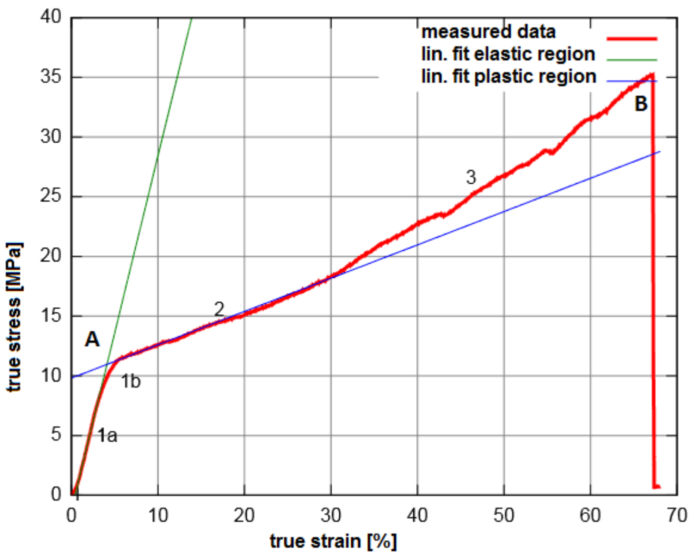


**Fig. 2.** – Load curve obtained from the tensile test of a hair

## MATERIALS AND METHODS

Two groups of Old Kladruber horses have been chosen for the study. First group consisted of the hairs of still non-discoloured horses born in 2015, the second group comprised the hairs of horses over 5 years of age. Horsehairs of 10 horses have been processed in all, namely 3 hairs from the mane of each horse. Hairs had been extracted at their roots; all hairs had been taken within one day. From this part, a 5 cm long sample had been separated, that had been recorded with an optical microscope with a digital camera for determining its diameter. From each snap, partial diameters have been measured in 5 locations, and overall diameter has then been established for each particular hair from them. After the imaging, hair sample had been fixed in the jaws of the mechanical testing machine Deform type 2 (see e.g. JELEN ET AL., 2014), and there it has been tested with a constant machine speed of 1 mm/min up to its breakage. All measurements on the testing machine have been carried out in constant relative humidity of 43–47 % and a constant temperature of 24–27 °C. From these measurements stress-strain curve data have been obtained that have then been processed with computational software. It can evaluate mechanical parameters like initial cross-section area, nominal and true Young's moduli, nominal linearity limit, elastic limit, ultimate stress, true ultimate stress, elongation to fracture, true relative elongation to fracture, total mechanical work necessary to break the matter, tensile toughness (the amount of energy necessary to break the matter per unit of the initial tensile volume), resilience (the amount of energy in a volume unit of the material loaded with $\sigma_{0.05}$ stress). Measuring procedure is an extension of the procedure that is described in more detail e.g. in SKŘONTOVÁ ET AL. (2011), SKŘONTOVÁ ET AL. (2014).

Young's modulus (E) is found from the Hook (linear) area of a load curve approximated by a linear function. Yield strength is determined by coordinates of the intersection of linear approximation of the load curve in a Hook area and the beginning of plastic zone. Ultimate strength is the maximum tension before a rupture of a hair, which was determined together with the fracture strain as the coordinates of the end point of the load curve, when the coordinate on the axis of independent variables is the fracture strain [%] and the coordinate on the axis of the dependent variables gives ultimate strength [MPa].

## RESULTS

Tab. 1 Mechanical and material properties of the horsehair. Y – young, A – adult, D – hair diameter, E – nominal elastic modulus, E' – true elastic modulus, σ – ultimate stress, σ' – true ultimate stress, ε – fracture strain, ε' – true relative elongation to rupture, W – total mechanical work necessary to break the hair, $W_A$ – toughness, $W_e$ – resilience.

For comparison, in previous literature, e.g. ŠIMKOVÁ ET AL. (2013), only E and E' are listed from the above mentioned quantities; their values agree with the current ones within the limits of the variance. Determination of all the other quantities is a new contribution of this work.

At 5% significance level, assuming normality, only diameter, cross-sectional area, volume, elongation to fracture and energy necessary to breakage do differ (f-test, t-test). The first three quantities are dependent though, thus cross-section and volume are omitted from further analysis for this reason and only diameter is followed hereafter.

For the remaining three quantities that differ provably statistically for the groups of discoloured and non-discoloured Kladruber horses, detailed comparison of distribution histograms is presented, each quantity for both groups of horses in one figure.

**Tab. 1.** – Contains measured mechanical and material properties of horsehair from discoloured and non-discoloured Kladruber horses.

| | *D*(μm) | *E*(GPa) | E'(MPa) | σ(MPa) | σ'(MPa) | ε() | ε'() | W(mJ) | $W_A$(MJ/m$^3$) | $W_e$(MJ/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|---|
| Y | 136±19 | 2.3±0.8 | 2.3±0.8 | 76±32 | 95±46 | 0.2±0.1 | 0.2±0.1 | 9±6 | 15±19 | 0.25±0.26 |
| A | 149±13 | 2.2±0.4 | 2.2±0.3 | 79±24 | 106±41 | 0.3±0.2 | 0.3±0.1 | 14±10 | 11±12 | 0.15±0.22 |

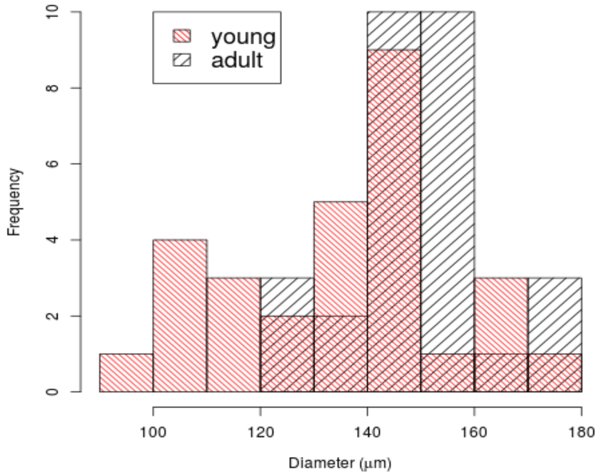


**Fig. 1.** – Distribution of horsehair diameter of adult (discoloured) and young Kladruber horses

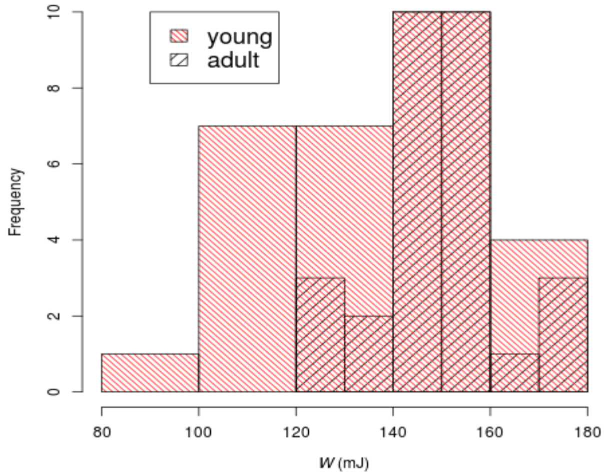


**Fig. 2.** – Distribution of total work necessary to break the hair of adult and young Kladruber horses

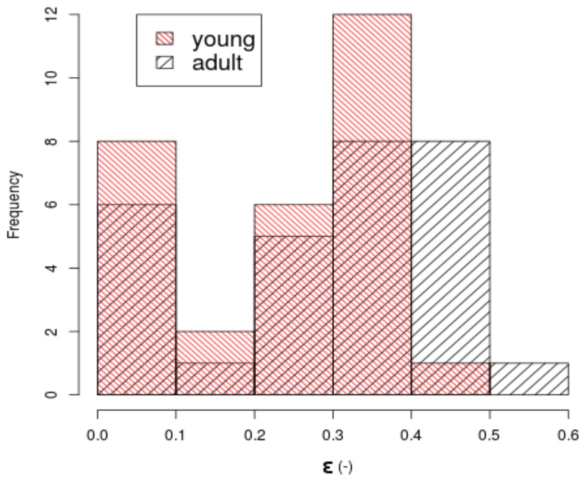


**Fig. 3.** – Distribution of horsehair fracture strain of adult and young Kladruber horses

**DISCUSSION**

Present experience shows that dark hairs are stronger than the light ones – e.g. BENZARTI ET AL., (2011), ŠIMKOVÁ ET AL. (2013), and similar behaviour could have been expected in this case also. The expectation that elasticity modulus of black horsehairs would be severalfold higher than the one of discoloured hairs did not prove true. Differences are only verifiable at three quantities, always in favour of discoloured horses over 5 years of age. Their values are always higher in mean value and besides more equal, i.e. with lower variance.

This is probably the reason why there are horsehairs of older horses used for technological use, e.g. for bow production. What is the advantage of black hair for the young horses is therefore in no way clear. The reason might be ethological, e.g. in the approach from the side of discoloured stallions or mares. No mechanical advantage of the black horsehairs in young horses has been found.

Authors are not aware of any previous measurements results on discolouring horsehairs in comparison to the black ones and they consider the results quite new, and in this sense no comparison to other works could be found.

## CONCLUSIONS

Although provable difference has been found in three mechanical and material parameters between discoloured and dark horsehairs of Old Kladruber horse, these differences are always in favour of whitened hairs, i.e. the ones of older horses. We consider this fact surprising, since in non-discolouring species' the advantages are always on the black biopolymers side.

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