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USE OF ANIONIC POLYACRYLAMIDE TO CHALLENGE LAND DEGRADATION THAT LED TO SLOPE INSTABILITIES: PRELIMINARY RESULTS

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EXTENDED ABSTRACT

Il cambiamento climatico continua a porre nuove sfide alla gestione del territorio ed alla conservazione del suolo tanto in ambiente urbano quanto in aree meno densamente popolate a vocazione agricola, a causa dell'intensificazione degli eventi meteorologici estremi ed in particolare degli eventi pluviometrici estremi, che sono la principale causa scatenante per erosione del suolo e frane superficiali (Chiang *et alii*, 2011), (Crozier, 2010). Questi fenomeni, che interessano generalmente i primi 2 metri di terreno, hanno un forte impatto su vaste porzioni di territorio che spesso includono pendii coltivati, causando danni seri ad economia locale ed infrastrutture, la perdita di quantità considerevoli di terreno fertile e minacciando vite umane (Fowze *et alii*, 2012), (Mallari *et alii*, 2016), più tutta una serie di costi indiretti (Galve *et alii*, 2016). In tempi recenti i polimeri, come la poliacrilamide (PAM), si stanno dimostrando validi strumenti per contrastare il deterioramento del suolo (Sojka *et alii*, 2007), e trovano frequente utilizzo come ammendanti oltre ad avere un ampio ventaglio di applicazioni.

Attraverso una ricerca bibliografica che ha coinvolto centinaia di articoli sono state raccolte informazioni relative all'uso della poliacrilamide per la gestione del suolo, al fine di sondare e testare le capacità di questo materiale nella stabilizzazione del suolo per la prevenzione delle instabilità superficiali. In seguito, due set campioni di suolo, costituiti rispettivamente da caolino e sabbia limosa, con tre differenti densità secche (comprese tra 1.2 e 1.6 g/cm^3), tre differenti valori di umidità iniziale (compresi tra il 5% ed il 40%) e cinque differenti tassi di applicazione del polimero (0%, 0.003%, 0.03%, 0.3%, e 1% in peso), sono stati ricostituiti in laboratorio per osservare gli effetti dell'applicazione della PAM sulle loro proprietà fisiche, volumetriche, meccaniche ed idrologiche. Il polimero, una poliacrilamide anionica in forma granulare, fornita da Micronizzazione Innovativa Srl, è stata applicata e miscelata manualmente con i campioni di suolo, che sono poi stati lasciati ad essiccare all'aria e pesati regolarmente per monitorarne il contenuto in acqua; prima di essere sottoposti alle analisi (caratteristiche volumetriche e limiti di Atterberg) secondo standard ASTM.

I risultati preliminari hanno mostrato che l'aumento della percentuale di PAM nei campioni ha generalmente comportato un aumento del limite liquido e dell'indice di plasticità degli stessi, causando allo stesso tempo un più graduale e regolare rilascio dell'umidità contenuta rispetto ai campioni non trattati. Questi risultati, unitamente alle informazioni fornite dalla letteratura in merito (Chen *et alii*, 2016), mettono in luce la possibile applicazione della poliacrilamide per il miglioramento delle caratteristiche del suolo che influiscono sulla predisposizione dei versanti ad essere interessati da instabilità superficiali, in un contesto di soluzioni sostenibili per la riduzione della suscettibilità, della pericolosità e del rischio da frana superficiale. Sarebbe comunque opportuno svolgere ulteriori test per indagare più a fondo e meglio comprendere le interazioni tra la poliacrilamide ed il suolo sul quale viene applicata e le conseguenze a lungo termine su quest'ultimo.

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ABSTRACT

Climate change is continuously posing new challenges to land management and conservation in built, populated and agricultural areas. Polymers such as polyacrylamide (PAM) offer a suitable tool to stem soil degradation, as well as having a wide range of applications. Informations on polyacrylamide's use related to soil management were gathered through a literature review involving hundreds of articles. Soil samples were reconstructed in laboratory to observe the effects of PAM application on their physical, volumetric, mechanical, and hydrological properties. Two sets of samples were reconstructed using kaolin and sandy loam soil, respectively, with three different dry densities (varying between 1.2 and 1.6 g/cm^3), three different initial water contents (varying between 5% and 40%) and five different polymer application rates (0%, 0.003%, 0.03%, 0.3%, and 1% by weight). The polymer, a granular anionic polyacrylamide, provided by Micronizzazione Innovativa Srl, has been manually applied and mixed with samples; then left to dry undisturbed. Preliminary results showed that the increase of PAM percentage in samples generally coincided with increase of liquid limit and plasticity index, causing at the same time a more gradual and regular release of water compared to untreated samples. These preliminary results highlight the possible application of PAM to improve other soil features which could impact on slope instabilities occurrence, in a frame of sustainable solutions for the reduction of landslides susceptibility, hazard and risk.

Keywords: polyacrylamide, soil stabilization, soil conservation

INTRODUCTION

Climate change is constantly posing new challenges to land management both in strongly anthropized and less populated agricultural areas. The intensification of extreme weather events such as extreme rainfall (Haque *et alii*, 2019) is becoming more and more common, and since these rainfall events are one of the major triggering factors for shallow landslides and soil erosion (Crozier, 2010; Chiang & Chang, 2011), even these phenomena will see an increase in their probability of occurrence (Gariano & Guzzetti, 2016; Rianna *et alii*, 2014). Shallow land degradation affecting the first 2 m of soil profiles has impacts on large portions of land including cultivated slopes, causing serious damage to local economy, infrastructures, the loss of considerable quantities of fertile soil and threatening human lives (Fowze *et alii*, 2012; Mallari, 2016), plus a wide variety of related indirect costs, such as the losses of productivity and of value of the land, the temporal loss in the serviceability of roads, the cost of health care for injured people and of legal actions (Galve *et alii*, 2016).

Land degradation induced by shallow slope instabilities can be countered through different structural and non-structural stabilization and remediation works, which aim to reduce the amount of destabilizing forces acting along the hillslope and/or to increase the shear strength properties of the slope soils (Arce-Mojica *et alii,* 2019; Bovolenta *et alii*, 2016). However, all these traditional remediation strategies show some critical issues: they can be expensive and applicable only at site-specific scale, with strong impacts on landscape and environmental continuity (Moos *et alii*, 2018), they often need a transition period, up to decades, to get positive effects on slope stabilization (Cammeraat *et alii*, 2005), or could lead to the loss of cultural heritage, landscape features and biodiversity of a territory with impacts even on socio-economic development (Arnaez *et alii*, 2011).

In this framework, the improvement of soil physical and geotechnical properties for limiting land degradation, correlated by an improvement of organic and fertility features, can be provided using additive materials, namely soil conditioners (Sojka *et alii*, 2007; Hähndel & Prün, 2009).

Nowadays polymeric materials such as polyacrylamide (PAM) are becoming more and more widespread and already have a wide range of applications; moreover, they also seem promising in preventing soil degradation, thus reducing the probability of greater damages on human economic activities, safety, and landscape. The aim of this work is to present the preliminary results on the assessment of changes in physical features of soils treated with PAM, with the aim to improve them in terms of slope stability.

MATERIALS AND METHODS

Soil samples were reconstructed in laboratory to observe the effects of application of anionic polyacrylamide (PAM) on their physical, volumetric, mechanical, and hydrological properties. First, two sets of samples were reconstructed using kaolin (Kaolin powder AKPrime CAPKN80 from Bal-Co spa, Table 1) and sandy loam soil (from Sabbie Sataf Srl, Table 1), respectively.

Sieves	PAM %	ASTM D2487
> 2000 µm	0	Medium sand
> 1000 µm	4.39	
> 250 µm	33.63	Fine Sand
> 125 µm	34.37	
> 75 µm	15.04	
< 75 µm	12.08	Silt

Tab. 1 - Granulometry of polyacrylamide, classified as a fine sand

All samples have been prepared by compacting the material in three layers in PVC cylinders, with a diameter of 9.5 cm and 15 cm high, with the aid of a compacting load. Each one of the three layers had the same initial water content and density, different for each sample. Density and water content were set up in the planning phase of the experiment and had different values for kaolin and silty sand samples; 10.79, 11.77 and 12.75 kN/m^3 were the densities assigned to kaolin along with initial water content of 10, 20 and 40%, while for silty sand were chosen

CAPKN80 – KAOLIN AKPrime (Bal - Co S.P.A.)		
Chemical Analysis	SiO_2	46.5 %
	Al_2O_3	37 %
	Fe_2O_3	0.5 %
	TiO_2	0.5-1.0 %
	CaO	0.2 %
	K_2O	0.3-0.8 %
	Na_2O	0.05 %
	P.F.	13.2 %
Granulometry	Laser < 2 µm	70-83 %
	Sieve > 45 µm	0.3 % max
Mineralogical Composition	Kaolinite	87.0 %
	Quartz	3.0 %
	Illite / Montmorillonite	7.0 %
	Feldspar	3.0 %
Other	pH	6.5-8.5
Selected Sand 113-25 (Sabbie Sataf s.r.l.)		
mm	00.20-00.35	

Tab. 2 - Specifics of samples constituent materials

11.77, 13.73 and 15.69 kN/m^3 along with initial humidity values of 5, 10 and 20%. An additional set of samples with five different polymer application rates (0%, 0.003%, 0.03%, 0.3%, and 1% by weight) has been reconstituted for both kaolin and silty sand. The polymer, a granular anionic polyacrylamide provided by Micronizzazione Innovativa Srl, has been manually applied and mixed with samples.

After preparation samples have been left to dry and constantly weighted to measure the variation in humidity (and of related parameters such as gravimetric and volumetric water content and unit weight). Kaolin samples alone have then been submitted to Atterberg Limits estimation, and volumetric characteristics have been measured both for kaolin and for silty sand samples. All these analyses were carried out according to ASTM standards.

RESULTS

Preliminary results showed that the increase of PAM percentage in samples generally coincided with the increase of liquid limit and plasticity index (Fig. 1), causing at the same time a more gradual and regular release of water compared to untreated samples (Table 3-4, Fig. 2-3). Not all soil-PAM mixtures exhibited higher PI and WL compared to those obtained for the untreated soil. All kaolin samples fell in the area OH-MH/CH, that identifies fat clays of high plasticity, and remained close to the A-line. Lower PAM percentages (0.003%) had little to no consequences on the Plasticity Index of samples, while with rising polymer percentages (0.03%) samples moved up (showing rising PI values consistent with data obtained by other works, Soltani *et alii*, 2022) on the delimitation line remaining

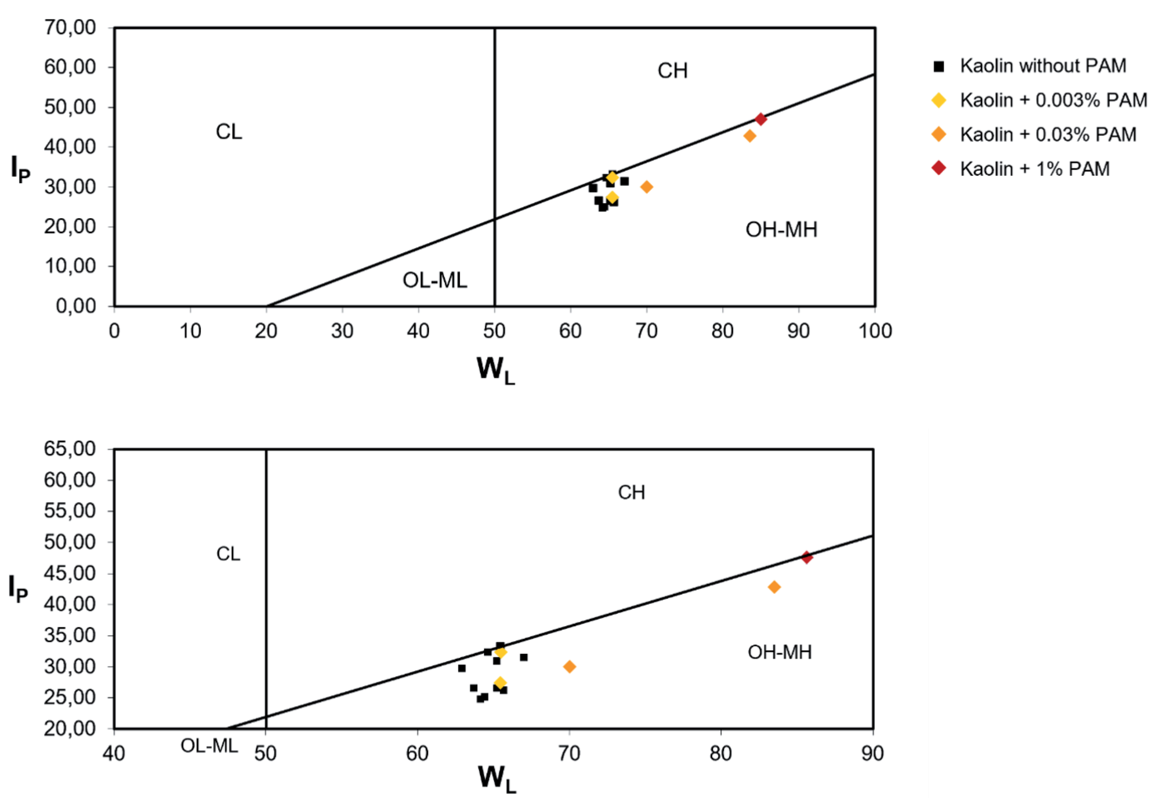

Fig. 1 - A: Casagrande Plasticity chart of analysed samples. B: particular of the same chart

Sample (IWC%, γd in g/cm³, PAM%)	Initial Water Content (%)	Final Water Content (%)	% Difference IWC-FCW (over 50 days)
F1 (20, 1.1, n/a)	20	0.67	96.65
F2 (20, 1.1, n/a)	20	0.62	96.9
F3 (20, 1.3, n/a)	20	0.70	96.5
F4 (40, 1.3, n/a)	40	1.56	96.1
F5 (10, 1.4, n/a)	10	0.93	90.7
F6 (20, 1.6, n/a)	20	0.95	97.62
F7 (40, 1.2, n/a)	40	0.96	90.5
F8 (10, 1.2, n/a)	10	0.97	90.3
F9 (10, 1.3, n/a)	10	0.79	92.1
F10 (20, 1.2, n/a)	20	1.01	94.95
F11 (40, 1.2, n/a)	40	1.93	95.17
F12 (10, 1.3, n/a)	10	0.82	91.8
F7 bis (10, 1.2, 0.003)	10	2.96	70.4
F22 (10, 1.2, 0.03)	10	3.14	68.6
F23 (10, 1.2, 0.3)	10	3.77	62.3
F24 (10, 1.2, 1)	10	4.65	53.5

Tab. 3 - Variations in kaolin samples water content over time, along with total % difference (FWC= Final Water Content and IWC=Initial Water Content)

Sample (IWC%, γd in g/cm³, PAM%)	Initial Water Content (IWC, %)	Final Water Content (FWC, %)	% Difference IWC-FCW (over 50 days)
F13 (10, 1.4, n/a)	10	1.88	81.2
F14 (20, 1.4, n/a)	20	0.47	97.65
F15 (10, 1.6, n/a)	10	0.45	95.5
F16 (10, 1.2, n/a)	10	0.34	96.6
F17 (20, 1.2, n/a)	20	0.37	98.15
F18 (20, 1.6, n/a)	20	0.59	97.05
F19 (5, 1.2, n/a)	5	0.39	92.2
F20 (5, 1.4, n/a)	5	0.45	91
F21 (5, 1.6, n/a)	5	0.45	91
F25 (10, 1.2, 0.003)	10	0.5	95
F26 (10, 1.2, 0.03)	10	0.51	94.9
F27 (10, 1.2, 0.3)	10	2.8	72
F28 (10, 1.2, 1)	10	2.55	74.5

Tab. 4 - Variations in silty sand samples water content over time, along with total % difference (FWC= Final Water Content and IWC=Initial Water Content)

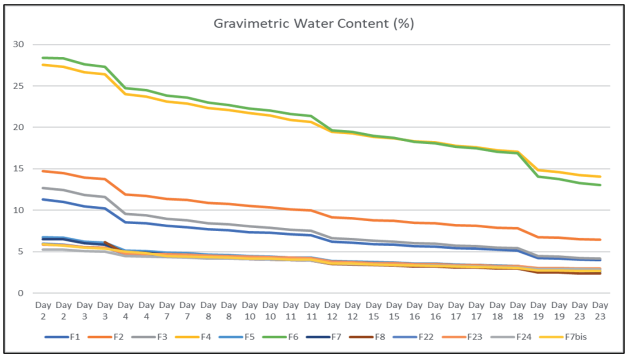

Fig. 2 - Gravimetric water content (%) of kaolin samples over time. The names of the samples in the legend refer to Table 3

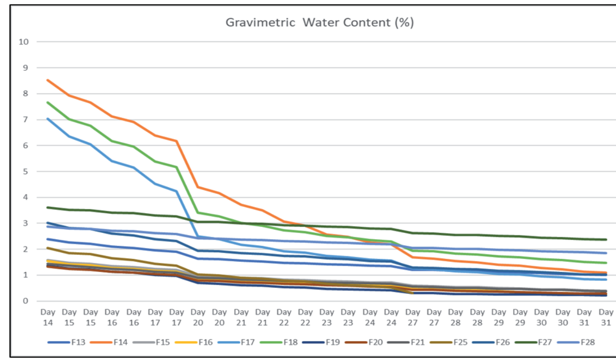

Fig. 3 - Gravimetric water content (%) of silty sand samples over time. The names of the samples in legend refer to Table 4

however on it even with the maximum PAM content (1%).

WL values for samples containing the lower PAM percentage (65.47) remained very close to the average of non-treated samples (64.66), while with rising PAM concentrations they also grew showing remarkably higher values (70.55 and 83.54 with 0.03% PAM and 85.64 for 1% PAM). These values should however be assessed with caution due to the behaviour of samples characterised by the presence of high polyacrylamide percentages. Even after various attempts it was not possible to obtain a value for the PI and WL of the samples bearing 0.3% (as well as for one bearing 1% PAM), as their behaviour remained viscous and sticky at the same time not allowing the experimenter to submit it to Casagrande Spoon. This is probably due to the high percentage applied, since the average in literature (among others Georgees *et alii*, 2016; Kebede *et alii*, 2020; Prats *et alii*, 2014; Sojka *et alii*, 2007) correspond to the 0.023% by weight, and suggest avoiding the use of PAM percentages higher than 1%, that could result in samples more difficult if not impossible to handle and with possibly unwanted effects on soil. Furthermore, PAM applied beyond a certain amount stops causing changes in soil properties and can actually become counter-productive (Majed, 2006).

However, these preliminary results, as well as those of other authors (Ajwa & Trout, 2006; Chen *et alii*, 2016; Yang *et alii*, 2019), shed light on the possible application of PAM to improve other soil features (i.e., erosion, infiltration rate, shear strength properties, water retention curve features) which could impact on slope instabilities occurrence, in a frame of sustainable solutions for reduction of landslides susceptibility.

CONCLUSIONS

The objective of this experimental work is to examine the effects of PAM treatment on soil's physical, volumetric, mechanical, and hydrological properties, and to present preliminary results. Accordingly, five soil-PAM mix designs (i.e., untreated soil and four PAM-treated samples) were examined for both kaolin and silty sand. For the PAM-treated cases, PAM quantities (i.e., mass of granular PAM by sample weight %) of 0%, 0.003%, 0.03%, 0.3%, and 1% were manually applied and mixed with samples.

Despite PAM addition causing a translation nearly parallel to the A-line depending on the quantity added, the original OH-MH/CH classification of unamended soil remained valid for all PAM treated cases (not all samples containing higher polymer rates were submitted to Atterberg Limits because of their behaviour).

Results are somewhat contrasting, as PAM would be an interesting and useful tool to reduce soils proneness to surface instabilities and land degradation by its ability to act as a stabilizer enhancing soil strength, preventing soil erosion (Chen *et alii*, 2016) and reducing its water content and absorption (Yang *et alii*, 2019). However, preliminary data to date show that PAM-treated samples would retain more water compared to untreated material, and that is confirmed by other works (Chen *et alii*, 2016), therefore further experiments should be conducted to obtain more various and robust data do compare and analyse.

The final aim would be to assess polyacrylamide capacity to improve soil features in terms of slope stability, and in this optic, it would be appropriate to conduct further research testing PAM on natural soils characterised by a more various composition compared to the ones reconstructed in laboratory.

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